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TELEPHONE SWITCHING TECHNOLOGY SURVEY.(U)

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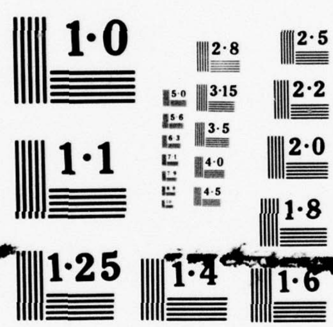
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OFFICE OF THE ASSISTANT SECRETARY OF DEFENSE
COMMUNICATIONS, COMMAND, CONTROL AND INTELLIGENCE

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TELEPHONE SWITCHING TECHNOLOGY SURVEY

CONTRACT MDA903 77 C 0263

Dittberner Associates, Inc.
Washington, D.C.

OFFICE OF THE ASSISTANT SECRETARY OF DEFENSE
COMMUNICATIONS, COMMAND, CONTROL AND INTELLIGENCE

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

I

INTRODUCTION

This constitutes the final report for the OASD, Communications Command, Control and Intelligence Contract Number MDA 903 77 C 0263, "Telephone Switching Technology Survey." The draft report was submitted to OASD, CCCI for review and the suggested changes have been incorporated into this final version.

A. SCOPE AND OBJECTIVES

The primary objective of this study was to provide a comprehensive survey of fully electronic telephone switching equipment which will be available as proven systems in the early 1980's. The equipment was to be evaluated against the general specifications of DOD general and special purpose tactical and nontactical, fixed and transportable switching requirements. The limitations of such equipment to meet these requirements, and the indication of the difficulty and likely delays in modifying the equipment to meet DOD requirements are to be defined.

Equipments in the general size range of approximately 100 to 5,000 subscriber/trunk lines were included within this scope. Emphasis was to be given to equipment developed by major free world telecommunication manufacturers with proven histories in the telephone switching field. Equipment was to be described technically with emphasis on their ability to pass up to 64 kilobits per second (Kbps) digital data speeds, signalling compatibility, reliability and maintainability, as related to DOD requirements. Operational capabilities were to be described to include ease of modification for U.S. DOD and NATO applications. Additionally, a more comprehensive listing of minor manufactured equipments likely to be in service by the 1980's is to be cataloged and briefly described.

B. LIMITATIONS

Several major limitations of the existing report should be identified. These include:

- Analysis of software capabilities to implement military subscriber and system features has not been adequately covered, although the suppliers have indicated their ability (or lack of ability) to easily implement these features within each system included in the survey.
- Not all systems which we were able to identify have been included in the survey, because of a lack of responsiveness from certain manufacturers. One major reason for this delay is a lack of understanding of the vocabulary utilized for military switching systems on the part of commercial PABX manufacturers.
- Initial procurement cost estimates which are included in this report are based upon larger size switching systems that are anticipated for procurement by the military. These are the only cost estimates which were available for Dittberner Associates for incorporation in this report, and were developed for a major multiclient study effort conducted previously. However, our contract did not specifically call for any cost estimates.

C. OVERVIEW OF RESULTS

The most general statement of results which can be made is that we were pleased to find that a number of commercial PABX and small central office systems were capable of meeting a majority of the identified needs for DOD switching programs now. We also discovered that:

- o Small switching systems (PABX) in the size range from 50 to 500 lines are being aggressively attacked by a number of major manufacturers with space division analog all electronic technology.
- o For the size range above roughly 500 lines, all digital PCM technology is dominating the field, with new announcements of systems being made almost on a monthly basis.
- o Pulse amplitude modulated systems and pulse width modulated systems for larger PABX applications are selling well, are achieving more field experience than PCM systems of equivalent size, and appear to be performing adequately. However, there is substantial evidence that these technologies will peak out within the next five years, and gradually be replaced with either solid state analog or PCM all-electronic technologies.

One of the major problems identified is the inability of nearly all of the current digital electronic systems surveyed to deal effectively with the CVSD voice switching problem. To meet this requirement, the solid state analog space division technology now appears to be more attractive. Significant problems also exist in the design of interfaces to permit all-digital electronic technologies to process up to 64 kilobits per second digital bit streams These are not considered to be insoluble technical problems, but rather ones involving modest development investment for specialized interfaces to handle synchronization, and bit stuffing for speeds lower than 64 kilobits per second. Here again, the solid state analog time division technologies have no problem passing up to 64 kilobits per second through the system, although only a few such switches provide, in their current matrix design, the necessary four-wire facilities typically required.

However, we should like to point out that there are substantial advantages in adopting PCM technology for certain of these military needs, particularly for the NCS work on post attack reconstitution of the U.S. DDD network, in terms of its capability to interface easily and effectively with the public dialed network in the United States. It would appear that many manufacturers will be producing PCM technology capable of dealing effectively with either 24- or 30-channel PCM carrier systems in the near future. For programs, such as the European Telephone System, and related programs, the use of PCM technology appears highly desirable, even though there may not be a requirement to interface with any significant number of digital carrier systems.

Most manufacturers appear to be optimistic concerning the interface with a wide range of signaling systems, through the development of specialized line/trunk interface hardware, and appropriate software modifications. We have been able to identify a number of changes which could be easily implemented by the commercial switching system manufacturers to substantially increase the availability of their commercial design systems. In general, we believe that most of the commercial systems covered in this survey could be upgraded to meet a realistic specification for the transportable van-mounted application, and clearly are adequate for benigned fixed installations. These improvements in commercial design philosophy would include:

- The use of ceramic-coated integrated circuit packages.
- Additional fungus protection on printed circuit boards and components, together with fungus resistance connectors.
- Use of duplicated main data bus (a high cost modification for systems not already incorporating this capability), likely with an on-site spare processor.
- Use of any one of the standard forms of redundant common controls utilized in commercial practice.
- Provision of additional switching matrix modules for certain segments of the switching matrix, which could be manually cable-connected in the event of a major failure in the active matrix module.
- The use of a computer-grade uninterruptable power supply for the smaller PABX systems which cannot operate from a 48 volt battery.

II

SURVEY OF SMALL ELECTRONIC TELEPHONE SWITCHES

A. SWITCHING NETWORK TECHNOLOGIES

The switches covered by this report are all "fully electronic" systems. This expression means that not only the common control is implemented entirely with solid state technology (all of the systems actually use "stored program" common control technology), but also the switching network (matrix) is built from solid state components. By definition, this excludes any switches with metallic crosspoints (relays, crossbar etc.). All of these switches have been designed specifically for applications ranging from public telephone networks to private corporate voice networks and commercial PABX functions. None of the switches were initially designed for a military environment, though some of them have been adapted for specialized military usage.

Therefore, these systems are intended to work with the following types of signals:

- Normal telephone analog voice, as well as analog modem signals.
- In the case of PCM switches, multiplexed digital trunk signals, either in the Bell T1 (1.544 megabits per second) format or in the European CEPT format (2.048 megabits per second).
- Switching of digital data, though possible with some systems, or relatively easily implemented in others, has not been emphasized by the designers, since there have been very few applications for switching of data in public or commercial voice networks as of yet.

Further, the standards presently adopted for the public network (and used in all commercial networks) do not have provisions for individually encoded nonmultiplexed PCM voice signals. Analog subscriber lines or trunks are converted to PCM either at the entrance to the switch or, in some cases, at a remote multiplexer. Transmission

between the multiplexer and the PCM switch is always through a time-division multiplexed line, using a format similar to that of the T1/D2 multiplexed trunk. Further, there is no "PCM digital telephone" (telephone instrument with built-in CODEC) in any public or commercial network.

Military telephone systems in many cases have to handle a great variety of signals. The most common types are:

- Normal analog telephone voice signals, as well as analog modem signals.
- CVSD encoded voice, either at 32 Kbps or at 16 Kbps, requiring usually four-wire subscriber circuits.
- Newer modes of encoded (and encrypted) voice, at 2.4 Kbps and, possibly at other speeds, some requiring four-wire loops.
- Six-bit PCM, including certain types of secure voice equipment, with 50 Kbps, using four-wire loops.
- Various data transmission speeds and formats.
- Eight-bit PCM according to the North American Standard is not used to any great extent as of today.

For the purpose of this report, it was agreed upon to focus on transmission of analog voice and digital data rates of 2.4, 4.8, 7.2, 9.6, 16, 32, 50 and 64 Kilobits per second through the switches. These data rates include all those used for CVSD and other military voice encoding schemes.

Multiplexed CVSD

All commercial PCM switches have ports on their digital switching networks which accept either T1/D2-D3 (24 channel) or CEPT (30 channel) multiplexed trunks directly, i.e. without external demultiplexing. The switching network performs the function of connecting any individual channel within any port with any other channel of the same or of a different port (or with a local subscriber loop).

Though various multiplexing schemes are in use with CVSD throughout the range of military telephone networks, few can be used with any of the switches covered in this report, or with any

commercial switch which we are aware of, without first demultiplexing of the CVSD multiplexed channel. PCM switches are limited to the T1 or CEPT format (which are entirely different from any established CVSD multiplexing standard). All other switches (non-PCM) lack the ability to handle individual channels of any digitally multiplexed signal separately. Some of them, however, might be able to transmit an entire CVSD multiplex through the switch without changes to the bit-sequence or content of the individual channels.

It should be pointed out that military telephone systems make use of leased (or, possibly, owned) T1 carrier lines in many instances. However, the usual type of operation is based on special military multiplexing equipment, which allows transmission of many different types of digital data, such as CVSD, data, and telex over a line using formats quite different from the Bell D2-D3 format. The reason for this, as is usually pointed out, is to make better use of the existing bandwidth of the T1 line. We are fully aware that, especially in tactical situations, bandwidth is much less available than in public telephone networks. But, we think that it might well be worthwhile to look into the cost trade-offs involved in permanently installed military networks. Possibly, the cost involved with choosing the standard Bell System PCM format (which requires more bandwidth, but which allows a fully integrated PCM transmission and switching system) is not higher than that of a system which needs special multiplexing and demultiplexing equipment at each switch.

In the following, the various matrix technologies used in the commercial switches will be discussed as background.

1. Electromechanical Crosspoint Matrix

Electromechanical switching networks (reed relay, crossbar, etc.) are specifically excluded from the scope of this report. However, they are of interest insofar as specifications for some military switches seem to be inspired by the knowledge of the possibilities of such technology.

A matrix built from high quality crosspoints, (reed relay or equivalent) if properly designed, should be easily capable of trans-

mitting 50 to 100 Khz or more. In addition to voice, this allows transmission of all of the data speeds which are of interest. Specifically, such a switch would not only be transparent to the particular data speed, but also to the specific format (word length, synchronous or not, or CVSD, etc.). In addition, the "line mode" (bipolar, diphase or other) used externally may be transmitted through the switch, since the crosspoints pass DC as well. (Different line interfaces for voice might be required). However, there are well known maintenance and noise problems connected with such crosspoints, which have caused manufacturers to develop fully electronic switches instead.

2. <u>Space Division Analog Matrix With Solid State Crosspoints</u>

In this technology type, the metallic crosspoints of a conventional switching network (for example, reed relays) have been replaced with semiconductor switches. Most switches for this purpose consist of SCR's (Silicon Controlled Rectifier), four-layer diodes or related devices. One such switch is required for each wire of the voice circuit. Usually one to four switches are packaged with part of the control circuitry within one package. SCR's and similar devices exhibit bistable behavior. They either present an extremely high resistance to the signal path or, after being "triggered," a very low resistance. Relatively involved control circuitry is needed with each crosspoint.

Some telephone switches use semiconductor analog switches instead of SCR's, either of the MOS or the FET (Field Effect Transistor) type. These switches are not inherently bistable. They have to be combined with a "flip-flop" in order to acquire this property. Their advantage over SCR's is that they do not need a constant forward D.C. current in order to maintain their conducting state, as SCR's do. Further, they lend themselves to large scale integration. Units have been demonstrated with up to 64 one-wire crosspoints, containing the necessary on/off "flip-flops" as well as part of the digital addressing logic.

Both types of switches present their own specific design difficulties. However, both types have been successfully used in actual products. The design of a switching network has to follow the same rules as with reed relays, since both types of crosspoints are equivalent as far as the network configuration is concerned. However, interfacing with subscriber loops and trunks requires a different approach from that common with reed relays. All semiconductor switches have to be isolated from the D.C. levels present on the subscriber lines, as well as from the relatively high ringing voltages. Therefore, special subscriber line and trunk circuits are necessary, which include transformer and other components to feed the battery voltage to the line, to apply ringing current and to keep both from the entrance to the switching network. In addition, all of the line and trunk supervision functions have to interface with these circuits. It is usually not possible to apply battery or ringing through a junctor. Dial pulses have to be detected at the line interface, only touch tone signals may be sent through the matrix.

These line circuits contain many components which, in reed relay networks, are needed once per junctor, but which now have to be installed once per line. Thus, a certain cost increase for this part of the system is unavoidable. In fact, this cost increase is more pronounced in local switches than in tandem switches, because the former have a higher ratio of lines to junctors than the latter.

Semiconductor switches are by no means without loss when in the conducting state. In multistage switching networks, amplifiers may have to be inserted in order to keep system insertion loss within specified limits. Though such solutions are quite feasible, there remains a problem of insertion loss tolerances, which accumulate whenever a whole telephone network is built with solid state switches of this kind. However, if only two or three switches of moderate size are inserted into the path of one call, this problem is not likely to become serious.

A further problem associated with solid state space division switches is their cost. Though sometimes said otherwise, it has not been possible to build a truly inexpensive semiconductor crosspoint. In our PROJECT ESS* study, we evaluated cost trends for various switching technologies for the next ten years, assuming typical 5,000 to 10,000 line central offices. The results showed that solid state space division switches will not be cost competitive with PCM switches during the 1980's and later. This seems to be borne out by the fact that new PCM switches are being introduced almost every month, but no new solid state space division switch in this larger size range has been announced in quite some time.

This picture changes if smaller switches are considered. Larger switches require more stages in the matrix (under similar line traffic conditions) than smaller ones, therefore, the number of crosspoints increases faster than proportionally to the number of lines. Going to small switches means that the cost of the crosspoints becomes less important as compared with the cost of other components (the common control). Also, the problem of insertion loss with its tolerances is alleviated, because fewer switching stages are required. We are sure that such considerations are responsible for the many new entries of small PABX's with solid state space division matrices. It is difficult to determine the size above which this technology becomes less desirable, but we think that the limit will be somewhere between several hundred and a very few thousand lines (in the case of a PABX).

Note: Since transformer coupling has to be employed on all line and trunk interfaces, a single crosspoint per wire pair can be used, with a common ground for all paths through the matrix. This is the design approach taken for example in the IBM 3750. It certainly reduces the cost of the crosspoints by cutting their number in half. But, it introduces a certain number of additional design problems, especially with line balance and crosstalk.

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*PROJECT ESS is a proprietary multiclient study on electronic switching systems conducted by Dittberner Associates, Inc.

Advantage of this Technology

- Combines the advantages of the mechanical crosspoint with the properties of electronic components (no wear, no contact noise, no generation of "spikes," etc.).
- Allows configuration of a switching matrix similar to those with reed relays, and is redundant at least to some degree against failure of individual crosspoints.
- Passes voice, as well as frequencies up to usually at least 100 Khz, and is good enough for data rates of up to 64 Kbps. Is transparent to data speed, word format, etc., but not to line mode (bipolar, diphase etc.), since D.C. is not transmitted through matrix. Data is likely to require special line circuits.

Disadvantages of this Technology

- Switches above a certain size (above 2000 lines) are likely to be expensive, bulky (when compared with TDM switches) and possibly high in power consumption.
- There are few commercial products in the larger size range to choose from.
- No real disadvantages for small units.

3. Switching Networks Using Pulse Amplitude Modulation (PAM)

In the last section, we have seen that solid state analog crosspoints allow transmission of signals with considerable bandwidth--well over 64 Kpbs. They further allow switching speeds many orders of magnitude higher than those possible with reed relays. This capability, which is not normally utilized in a solid state space division matrix, makes it possible to build a much more cost effective switch by adopting the design principle of time division switching.

It can be shown mathematically that all information necessary to faithfully reproduce a voice signal with limited bandwidth is contained in amplitude samples taken periodically at about twice the frequency of the upper limit of the signal bandwidth. For telephony purposes, it is generally considered adequate to use a sampling rate of 8 KHz.

Separate paths for both directions of a call are provided within the matrix. Therefore, PAM switched are essentially of a four-wire configuration. Normal subscriber line interfaces, as well as those for two-wire trunks, contain a hybrid circuit for conversion between two- and four-wire paths in addition to the means for battery feed, application of ringing current and line supervision.

Each subscriber may be connected periodically with an "internal highway" or bus. There is one bus for each direction. Typically, a talking subscriber would be connected with the bus 8,000 times per second. During the rest of the 1/8,000 second, 63 other subscribers may be connected with the same bus.

A second series of crosspoints operate in such a way as to route each analog speech sample to the destination subscriber circuit. Samples are assigned each to a specific "timeslot," with the sequence being repeated once every 1/8,000 second. The individual pulse train is received at the destination subscriber circuit and demodulated. The first step is the application of a "sample-and-hold" circuit, then a set of filters smoothes out the resulting waveform. It should be noted that relatively elaborate filters are needed at the transmitting side (before converting to PAM), in order to properly limit the bandwidth. Here, the same considerations apply as explained in Chapter IV about PCM subscriber.

The simple switch described above can support 64 calls simultaneously. If 120 subscribers were connected to the bus, we would have created a 64 Erlang nonblocking switch. Several hundred subscribers and trunks may be accommodated, each with its own subscriber circuit and set of crosspoints, reducing the availability of the matrix for each line. The concentration thus achieved is due to the fact that only 64 out of the total number of stations may get access to the bus at any time.

The crosspoints are actuated according to information stored in the "control store." For each "time slot," this store contains information about the addresses of the crosspoints to be closed. This information is read out periodically and used to control the status of the crosspoints. The content of the control store (usually a fast semiconductor memory) is altered by the common control, making it possible to set up and release calls. It should be noted, however, that call connections can be maintained indefinitely without requiring action of the common control.

A switch with a higher traffic rating may be built by using a higher number of "time slots" in the bus. There is, however, a limit to this number, caused by the limited speed with which PAM samples can be handled by the solid state crosspoints.

The scheme in a "time switch" needs, of course, a more elaborate control store, since the addresses of the space division crosspoints to be actuated during each "time slot" have to be stored. Also, more complicated software routines are necessary in the common control in order to route calls through such a network.

Although the control circuitry of the matrix tends to be somewhat more complex, there usually is quite an advantage in cost, space requirement and power consumption. There are two obvious drawbacks: one is the increased complexity of the subscriber line circuits, which include all functions necessary in a PCM subscriber circuit, except for the CODEC. The other is the limitation of the bandwidth to the normal voice band (about 300 to 3500 Hz). This makes it difficult to transmit digital data directly through the PAM switch. While the first difficulty can be overcome by proper design, the data speed limitation is more serious, particularly for the range of applications considered in this report.

Of the two PAM systems in our survey, the WESTERN ELECTRIC DIMENSION, does not now include any direct digital data capability (except for allowing transmission of analog modem signals). The T&N 6030 (a similar design), however, includes the capability

to transmit 9600 bits per second over the matrix, using a special interface. Higher data rates can be accommodated in the 6030 (which is offered in configurations for data gathering and data distribution) in a special minicomputer-based data switch attached to the telephone switch. However, experimental versions of the T&N 6030 have been evaluated which transmit an eight-bit word serially within one PAM "time slot." Thus, data up to 64 Kbps, as well as PCM, can be handled.

A time-multiplexed matrix as described here lacks the inherent redundancy of a space division network. However, because of the small number of crosspoints used, the whole matrix may be duplicated for redundancy, at least in smaller configurations. In a larger system, duplication of central sections may be sufficient, if done in such a way that failure of any portion will affect only a given small number of lines.

Advantages of this Technology

- Fewer components than solid state space division, therefore higher reliability
- Less space required, less power consumed for the same reason.
- No quantization noise as in PCM systems.
- A very simple conference bridge is possible.

Disadvantages of this Technology

- Difficulty of switching digital data directly.
- Though WESTERN ELECTRIC DIMENSION and T&N 6030 seem to be very successful, we anticipate that this technology may well "peak out" within the next five years. With the availability of new low cost PCM CODEC's, there is not much cost advantages left for PAM.

4. PCM Switching Networks

Principles of PCM switching have been described so often in the literature that only a few notes should be sufficient. Switches are

built either as pure "time" (T) switches (in smaller configurations), or more usual, with "time-space-time" (T-S-T) networks. Other configurations are possible, but these are used only in systems much larger than those covered in this report.

Configurations of the "time" and the "time-space-time" PCM switching networks are the same as shown for the PAM matrix. The essential difference from the latter is that in the case of the PCM PCM switch each amplitude sample is encoded into a proper PCM format (μ=255 in North America, and A-law in Europe) and decoded in the subscriber circuit at the other end of the matrix. There is, of course, a difference in the requirements for the crosspoints. While the PAM crosspoint has to transmit samples of varying amplitude, the PCM the PCM crosspoint only handles logical levels. Therefore, a logic gate is sufficient in this case.

Further, the information contained in one PAM sample is encoded in an eight-bit word in the case of PCM. These eight bits may be transmitted serially through the matrix, thus increasing the pulse rate to eight times that of an equivalent PAM system. The highest serial data speed commonly used is 8.192 megabits per second, which is equivalent to 128 time-slots on an "internal highway" (8,000 samples per second multiplied with eight-bits per sample, times 128 samples per frame). The limiting factor is not so much the speed with which the crosspoints can be switched, but the speed of the control store and of the control electronics which applies the control information to the crosspoints. Although at least twice the speed of eight Mbps is technically feasible, higher numbers of "time-slots" are usually achieved, if considered necessary, by transmitting four or eight bits in parallel. Thus, the same configuration of crosspoints has to be provided four or eight times in parallel, establishing separate paths for each of the four or eight bits. Since the control store is only needed once the overall cost of the switching network only increases moderately.

As in the case of a PAM switch, small configurations are usually designed as pure "time" networks, while larger ones are "time-space-time" networks. So far, there is not much give and take between PAM and PCM technology. While PCM avoids the more expensive analog crosspoints, it needs CODEC's instead of the very simple PAM modulators and demodulators. But the real appeal of PCM technology for use in the future public telephone network lies in the elegance with which concepts of integrated switching and transmission, as well as of distributed switching, may be implemented. Most of the new generation of PCM products for use in public networks is designed according the principles outlined below.

Integrated Transmission and Switching and Distributed Switching

The heart of most modern PCM switches is a T-S-T network which accepts multiplexed digital trunks of the North American Tl (24 channel) type or of the European CEPT (30 channel) type. One "time slot interchange" (time switch) usually accepts one or more such multiplexes and distributes the individual channels into the "time slots" of an "internal highway." Some form of time multiplexed space switch then distributes the information in the "internal highways" to the other time slot interchanges. Such a switching network is either fully nonblocking, or has at least a very high availability. With the proper type of software in the common control and the right type of signalling interfaces, it can serve as a toll office or tandem. And, since it accepts digitally multiplexed trunks directly, it allows integrated transmission and switching for this type of application.

Local loops can be connected to such a switch in the following manner. A local or remote concentrator is used which consists of a number of PCM subscriber line circuits (see Chapter IV about design problems of PCM subscriber line circuits), as well as circuitry to multiplex the digital inputs and outputs of these into one or more Tl (or CEPT) multiplexes. If two Tl schemes together with 48

channels are used, 100 to 500 subscriber lines may be attached to such a concentrator group, depending on the concentration factor desired. Concentration is usually done on the digital side, but some European systems use space division concentrators on the analog (subscriber) side.

The subscriber line concentrator may be installed at the site of the switch, with the multiplexed digital side interfacing directly with the digital trunk ports of the main switching network. Or, it may be used as a remote subscriber concentrator. In this case, not only T1 (or CEPT) span terminating circuitry is included, but usually also provision to switch calls between subsribers of the same concentrator locally. These switching capabilities are either remotely controlled from the common control of the main switch or, in some instances, independent local control is provided in such a way that calls can be switched independently if the line to the main switch is out of order.

This aspect of today's PCM technology allows two important conclusions:

- Integrated transmission and switching is possible right now, as well as is distributed switching.
- The boundaries between the formerly well defined applications of Class 4 offices, Class 5 offices, and subscriber line carrier systems are becoming blurred. It is now possible, for example, to have a toll switch with attached local subscriber concentrators, as well as with remote concentrators. Thus, we have part of the Class 5 function combined with a Class 4 switch, while the rest of it is distributed all over the landscape.

Note: Any port capable of accepting digitally multiplexed trunks can be adapted to accept analog trunks, either with a special interface card provided by the manufacturer or by installing standard channel bank equipment with the switch.

Circuit Switching of Data

PCM switches are designed to handle 64 Kbps digital data for each encoded voice channel. Unfortunately, however, commercial switches have only digital trunk interfaces designed to accept multiplexed trunk channels.

It appears to be quite easy to design a digital subscriber interface, capable of accepting 64 Kbps for transmission over the switching network. Lower rates could be accommodated using bit-stuffing techniques. Problems of synchronization with the internal clock of the switch have to be solved, but are certainly within the range of the state-of-the-art.

Advantages of this Technology

- Requires much less space and power than solid state space division. More reliable, because of fewer components.
- More easily adapted to circuit switching of data than PAM.
- Supports principles of integrated switching and transmission, as well as of distributed switching.
- Cost is expected to decrease rapidly over the next several years. PCM is likely to be the least expensive technology for switches in the 5,000 to 10,000 line range in the mid-1980 time frame.
- There is a constantly increasing range of commercial PCM products to choose from.

Disadvantages of this Technology

- Adaptation for use with digital data, CVSD, etc. not as easy as with solid state space division.
- PCM switches may be adapted for use in military CVSD systems. However, this will interface, at least to some degree, with the capability to support the principles of integrated switching and transmission and of distributed switching.

5. Switching Networks Using Pulse Width Modulation (PWM)

It is possible to use pulse width modulation in the same way as PAM. Samples of the voice signal are taken periodically and their amplitude converted into the width of a corresponding pulse. The modulator necessary to do this is only slightly more complex than that one required for PAM. The demodulator is of about the same degree of complexity.

We have only two product lines in our survey which use PWM. One, CHESTEL, uses PWM in the same way PAM is used. That is, they use a time division switching matrix. The advantage over PAM is that the crosspoints and all other PWM carrying elements can be built from logic gates--no special analog crosspoints are needed.

The other product line is that of DANRAY. DANRAY uses line and trunk circuits containing free-running PWM modulators (not synchronized with any central clock) and asynchronous demodulators. The switching network is of the space division type, not time-division multiplexed. It consists of crosspoints which are logic gates (TTL).

Note: Logic gates can transmit PWM because the information is contained in the duration of the pulse, not in its amplitude, as with PAM. Logic gates cannot transmit varying amplitudes. Analog crosspoints can.

Cost Aspects of the DANRAY PWM Technology

Logic gates are by far the least expensive crosspoints of any technology, including reed relay, analog solid state and crossbar.

While PWM subscriber and trunk circuits need all the components around 20 KHz, as compared to the standard eight KHz PCM sampling rate, this higher sampling rate is possible because a non-time-division matrix is used.

Circuit Switching of Data

The CHESTEL PWM time-division switch has a built-in capability to switch data up to a certain speed. Constraints are very similar to those in PAM systems.

The digital space division matrix used by DANRAY is completely transparent to any digital bit stream up to at least 100 Kbps. The only requirement is the provision of an adapater to convert the line mode (bipolar, diphase or other baseband signal) to TTL logic levels and back.

Advantages of this Technology

- o CHESTEL Technology:
  - Same as outlined under PAM
- o DANRAY Technology:
  - Inexpensive and compact, even in larger configurations, when compared with solid state analog space division.
  - All data speeds, CVSD, etc. easily accepted up to at least 64 Kbps. No synchronization problems.
  - No quantisizing noise as with PCM.
  - Very simple conference bridge possible with PWM.

Disadvantages of this Technology

- o Only these two competitive products, not many new products expected. Most suppliers assume that PCM is the way to go for the future for any switch with at least 500 lines.

B. SUMMARY PRESENTATION OF SYSTEMS BY CLASS

The following tabulations are provided as a summary of the various systems offered by the different manufacturers. The systems are divided into four groups: PCM systems, PWM systems, PAM systems, and solid-state analog systems. A discussion follows for each of these systems with their advantages and disadvantages identified.

A key for the abbreviations used in the following summary tables is provided below:

AV	=	Available
NA	=	Not Available
IS	=	In Service
EI	=	Easily Included
DI	=	Difficult to Include
RE	=	Remote
N	=	No
Y	=	Yes
L	=	Lines
T	=	Trunks
CO	=	Central Office
PABX	=	Private Automatic Branch Exchange
TD	=	Tandem

SUMMARIZATION OF PCM SYSTEMS
Offered by Manufacturers

Manufacturer/Model	Application	Traffic Capacity (Erlangs) Max.	Min.	Economic Size-Lines or Trunks Max.	Min.	Engineered Traffic per Line or Trunk (Erlangs) Max.	Min.	Busy Hour Calls (000's) Max.	Min.	Busy Hour Call Attempts (000's) Max.	Min.	Assumed Average Holding Time (Seconds)
CITCOM E10	CO	3,000		30,000 (L)	5,000 (L)	0.35 (L)	0.1 (L)	90	25	126	35	120
CITCOM E10	PABX	1,500	150	15,000 (L)	1,000 (L)	0.35 (L)	0.1 (L)	50	4	100	15	120
COLLINS RADIO DTS	TD	712		1,424 (T)	250 (T)	1.0 (L)	1.0 (L)	14	14	18	18	240
GTE AUTOMATIC ELECTRIC GTD-120	PABX	45		120 (L)		L:25 T:5		0.8		1.48		100
NORTH ELECTRIC DSS-1	CO	15,000		12,000 (L)	1,000 (L)	L:01 T:0.8		70				200
NORTHERN TELECOM SL 1	PABX	1,170		5,000 (L)	200 (L)	Var.	Var.	11	11	13	13	100
ROLM CBX	PABX	127.8	70	800L (L)	100L (L)	L: .3 T: .7	L:0.3 T:0.7	3.6	2.1	4.5	2.7	120
STROMBERG-CARLSON Century DCO	CO	2,816	88	20,000 (L)	20L (L)	L:1.0 T:1.0	T:0.7	24	12	31.2	15.6	180
TRW VIDAR ITS 4, 4/5, 5	TD,CO	1,500		13,000 (L)		L:0.1 T:1.0		20	10	27	13	
WESCOM 580 DSS	PABX	3,000		2,400 (L)	80 (L)	L:1 T:1	L:1 T:1	18	18			150

PCM SYSTEMS

Manufacturer/Model	Application	Internal Call Loss Probability (Percent)	Matrix is Non-blocking	No. of Lines or Trunks Per Matrix Module	Multi-processor	Operating Temperature (°C) From	To	Range of Humidity (Percent) From	To
CITCOM E10	CO		N	12/16L 30T	Y	10	35	20	80
CITCOM E10	PABX		N	12/16L 30T	Y	10	35	20	80
COLLINS RADIO DTS	TD	NA	Y	24T	N	10	29	20	80
GTE AUTOMATIC ELECTRIC GTD-120	PABX	2.0	N	40L	N	7	40	20	80
NORTH ELECTRIC DSS-1	CO	0.1		4L	N	10	50	5	95
NORTHERN TELECOM SL 1	PABX	0.01	N	4L 2T	N	0	40	20	80
ROLM CBX	PABX	1.0	N	8L 4T	N	0.0	50	20	80
STROMBERG-CARLSON Century DCO	CO	1 0 (2.0)	N	30L 30T	N	10	27	20	60
TRW VIDAR ITS 4, 4/5, 5	TD,CO	0.0	Y(TD)	24L 16T	N	0	50	10	90
WESCOM 580 DSS	PABX	0.0	Y		Y	10	40		

PCM SYSTEMS

Manufacturer/Model	Application	Fan Required: Entire Switch	Fan Required: Common Control	Air Conditioning Required	Fungus Protection	Dust Protection	Power Consumption: Busy Hour (KW)	Power Consumption: Slack Hour (KW)	Voltage and Range From	Voltage and Range To
CITCOM E10	CO	N	N	Y	N	Y	(for 1,000L) 1.7	1.4	48DC 42.7	54
CITCOM E10	PABX	N	N	Y	N	Y	(for 1,000L) 3.7	3.5	48DC 42.7	54
COLLINS RADIO DTS	TD	N	Y	Y			16.8		115/240 or 48DC	
GTE AUTOMATIC ELECTRIC GTD-120	PABX	N	N	N	N	N	1.4	0.5	115AC 100	130
NORTH ELECTRIC DSS-1	CO	N	N	N	N	Y	(for 1,000L) 4	3	44	56
NORTHERN TELECOM SL-1	PABX	N	Y	N	N	N	(for 1,000L) 7	63	11oAC	121
ROLM CBX	PABX	Y	Y	Y	N	N	2.0	2.0	115AC 103.5	126.5
STROMBERG-CARLSON Century DCO	CO	N	Y	Y	Y	Y	20 (for 10,000L)	20	48DC 42	56
TRW VIDAR ITS 4, 4/5, 5	TD,CO	N	N	N	N	Y	(for 10,000L) 19	14	-48DC 44	54
WESCOM 580 DSS	PABX	N	N				7.2 (For 2,400L)		-48DC 44	54

PCM SYSTEMS

Manufacturer/Model	Application	Reliability: Year per 1 hour of Downtime	Reliability: MTBF (Hours)	Reliability: MTTR (Hours)	Installation Factors: Frame Height (mm)	Installation Factors: Average Floor Loading (Kg/m^2)	Configuration: Max. (Lines) (per m^2)	Configuration: Min. (Lines) (per m^2)	Fully Connectorized
CITCOM E10	CO	27	17	3	3,000	500	200	80	N
CITCOM E10	PABX	27	18	1.30	3,000	500	120	40	N
COLLINS RADIO DTS	TD				1,753	244	80	24	Y
GTE AUTOMATIC ELECTRIC GTD-120	PABX		5,000	0.25	1,245				Y
NORTH ELECTRIC DSS-1	CO	20	999	0.5	2,600	600	110	36	Y
NORTHERN TELECOM SL 1	PABX	1		0.5	1,800	550	160	130	Y
ROLM CBX	PABX				1,651	422.6	153	115	Y
STROMBERG-CARLSON Century DCO	CO	40	360	0.5	2,440	740	104	11	Y
TRW VIDAR ITS 4, 4/5, 5	TD,CO	20	912	1.0	2,400	450	50	7	Y
WESCOM 580 DSS	PABX	20			1,830				Y

PCM SYSTEMS

Manufacturer/Model	Application	Subscriber Line Interface: Analog 2-wire	Analog 4-wire	Maximum Loop Resist (Ohms)	Echo Return Loss (db)	Singing Margin (db)	CVSD	CVSD Bit Rate (Kbps)
CITCOM E10	CO	Y	N	2,200	16	---	N	------
CITCOM E10	PABX	Y	N	2,200	16	---	N	------
COLLINS RADIO DTS	TD	NA	NA	NA	NA	NA	N	------
GTE AUTOMATIC ELECTRIC GTD-120	PABX	Y	N	1,200	25	20	N	------
NORTH ELECTRIC DSS-1	CO	Y	N	3,200	--	18	N	------
NORTHERN TELECOM SL 1	PABX	Y	N	1,000	20	16	N	------
ROLM CBX	PABX	Y	N	600 or 1,200	20	16	N	------
STROMBERG-CARLSON Century DCO	CO	Y	Y	1,900	24	17	N	------
TRW VIDAR ITS 4, 4/5, 5	TD,CO	Y	Y	1,300	24	17	N	------
WESCOM 580 DSS	PABX	Y	Y	1,000			N	------

PCM SYSTEMS

Manufacturer/Model	Application	Trunk Line Interfaces: Analog 2-wire	Analog 4-wire	CVSD	CVSD Multiplex	CVSD Bit Rate (Kpbs)	PCM Multiplex	PCM Bit Rate (Kpbs)
CITCOM E10	CO	Y	Y	N	N	----	Y	2,048
CITCOM E10	PABX	Y	Y	N	N	----	Y	2,048
COLLINS RADIO DTS	TD	Y	Y	N	N	----	Y	1,544
GTE AUTOMATIC ELECTRIC GTD-120	PABX	Y	N	N	N	----	Y	1,544
NORTH ELECTRIC DSS-1	CO	Y	Y	N	N	----	Y	1,544
NORTHERN TELECOM SL 1	PABX	Y	Y	N	N	----	Y	1,544 (2,048)
ROLM CBX	PABX	Y	Y	N	N	----	N	-----
STROMBERG-CARLSON Century DCO	CO	Y	Y	N	N	----	Y	1,544 (2,048)
TRW VIDAR ITS 4, 4/5, 5	TD, CO	Y	Y	N	N	----	Y	1,544
WESCOM 580 DSS	PABX	Y	Y	N	N	----	N	1,544

PCM SYSTEMS

Manufacturer/Model	Application	Transmission Characteristic Analog, Intraoffice: Frequency Response (Hz) From	To	Maximum Data Rate with Modem (Bits/Second)	Net Loss (db)	Digital: Direct Digital Data Rate (Kbps)	Components, Duplicated for Reliability: Common Control	Matrix	SLU	Manual Patch-Through Possible
CITCOM E10	CO	300	3400	4,800	1.0	64	Y	N	N	N
CITCOM E10	PABX	300	3400	4,800	1.0	64	Y	N	N	N
COLLINS RADIO DTS	TD	300	3400	-----	(variable)	64	Y (2)	N	N	Y
GTE AUTOMATIC ELECTRIC GTD-120	PABX	200	3400	Not Recommended	5.5	No	N	N	N	N
NORTH ELECTRIC DSS-1	CO				0.5	--	Y	Y	Y	Y
NORTHERN TELECOM SL 1	PABX	200	3500	4,800	1.0	--	Y (2)	N	N	N
ROLM CBX	PABX	300	3400	4,800	1.0		Y (2)	Y (2)	N	N
STROMBERG-CARLSON Century DCO	CO	200	3400	4,800	0.5	--	Y (2)	Y	Y	(Y)
TRW VIDAR ITS 4, 4/5, 5	TD,CO	200	3400	9,600	2.0	64	Y (2)	Y (2)	N	Y
WESCOM 580 DSS	PABX	300	3400		(variable)	No	Y (2)	Y (4+1)	N	N

PCM SYSTEMS

Manufacturer/Model	Application	Signalling and Supervision — Local: DC Dial Pulse	Touch Tone	DC Neon Dial	AC Dialing	VF 2280Hz	VF 600/750Hz	Interoffice: CX	DX	Decadic	E&M	Loop	MF	MFC
CITCOM E10	CO	Y	Y	N	Y	Y	Y	N	N	Y	Y	Y	Y	Y
CITCOM E10	PABX	Y	Y	N	N	N	N	N	N	Y	Y	Y	Y	Y
COLLINS RADIO DTS	TD	Y	Y	N	N	N	N	N	N	N	Y	Y	Y	N
GTE AUTOMATIC ELECTRIC GTD-120	PABX	Y	Y	N	N	N	N	N	N	N	Y	Y	Y	N
NORTH ELECTRIC DSS-1	CO	Y	Y	N	N	N	N	Y	Y	Y	Y	Y	Y	(Y)
NORTHERN TELECOM SL 1	PABX	Y	Y	N	N	N	N	N	Y	Y	Y	Y		N
ROLM CBX	PABX	Y	Y	N	N	N	N			Y	Y	Y	N	N
STROMBERG-CARLSON Century DCO	CO	Y	Y	N	N	N	N	Y	Y	N	Y	Y	Y	Y
TRW VIDAR ITS 4, 4/5, 5	TD,CO	Y	Y	N	N	N	N	Y	Y	Y	Y	Y	Y	N
WESCOM 580 DSS	PABX	Y	Y	N	N	N	N				Y	Y	Y	N

PCM SYSTEMS

Manufacturer/Model	Application	Signalling and Supervision Interoffice: SF-2600Hz	CCITT #4	CCITT #5	CCITT #6	CCITT #7	PCM T1	PCM CEPT	Other	Interface With Other Systems: AUTOVON	NATO	AN/TTC38
CITCOM E10	CO	Y	N	N	N	N	N	Y		N	N	N
CITCOM E10	PABX	Y	N	N	N	N	N	Y		N	N	N
COLLINS RADIO DTS	TD	N	N	N	N	N	Y	N		Y	Y	Y
GTE AUTOMATIC ELECTRIC GTD-120	PABX	N	N	N	N	N	Y	N		N	N	N
NORTH ELECTRIC DSS-1	CO	N	N	N	N	N	Y	N		N	N	N
NORTHERN TELECOM SL 1	PABX	N	N	N	N	N	Y	N		Y	N	N
ROLM CBX	PABX	N	N	N	N	N	N	N		N	N	N
STROMBERG-CARLSON Century DCO	CO	Y	Y	Y	Y		Y	Y		(Y)	(Y)	N
TRW VIDAR ITS 4, 4/5, 5	TD,CO	Y	N	N	N	N	Y	N		N	N	N
WESCOM 580 DSS	PABX	N	N	N	N	N	Y	N		Y	N	N

PCM SYSTEMS

Manufacturer/Model	Application	Interface With Other Systems: AN/TTC39	Germany	France	Belgium	Holland
CITCOM E10	CO	N	N	Y	N	N
CITCOM E10	PABX	N	N	Y	N	N
COLLINS RADIO DTS	TD	N	N	N	Y	Y
GTE AUTOMATIC ELECTRIC GTD-120	PABX	N	N	N	N	N
NORTH ELECTRIC DSS-1	CO	N	N	N	N	N
NORTHERN TELECOM SL 1	PABX	N	Y	Y	N	N
ROLM CBX	PABX	N	N	N	N	N
STROMBERG-CARLSON Century DCO	CO	N	N	N	N	N
TRW VIDAR ITS 4, 4/5, 5	TD,CO	N	N	N	N	N
WESCOM 580 DSS	PABX	N	N	N	N	N

PCM SYSTEMS

Manufacturer/Model	Application	Military System Features					
		Five Levels of Precedence Service	Fixed Directory Translator Table	Conference			Secure Call Mode/Key Conversion
				Progressive	Preprogrammed	Broadcast	
CITCOM E10	CO	EI	IS	AV	AV	EI	N
CITCOM E10	PABX	EI	IS	IS	IS	EI	N
COLLINS RADIO DTS	TD	IS	IS	IS	IS	IS	DI
GTE AUTOMATIC ELECTRIC GTD-120	PABX	IS	NA	IS	DI	DI	DI
NORTH ELECTRIC DSS-1	CO	EI	IS	AV	AV	AV	DI
NORTHERN TELECOM SL 1	PABX	AV	AV	AV	DI	N	EI
ROLM CBX	PABX	DI	DI	IS	DI	DI	DI
STROMBERG-CARLSON Century DCO	CO	IS	EI	EI	EI	EI	EI
TRW VIDAR ITS 4, 4/5, 5	TD,CO	EI	EI	EI	EI	EI	DI
WESCOM 580 DSS	PABX	IS	EI	IS	IS	EI	DI

PCM SYSTEMS

Manufacturer/Model	Application	Military System Features				Numbering Plan	
		Direct Access Service	Up to 100 Class-of-Service Marks	Zone Restrictions	Circuit Switching of Data	Unrestricted Numbering	Max No.of Digits
CITCOM E10	CO	AV	AV	AV	AV	AV	16
CITCOM E10	PABX	IS	AV	AV	AV	IS	16
COLLINS RADIO DTS	TD	IS	AV	IS	IS	IS	5
GTE AUTOMATIC ELECTRIC GTD-120	PABX	EI	DI	EI	DI	DI	3
NORTH ELECTRIC DSS-1	CO	AV	IS	IS	AV	IS	16
NORTHERN TELECOM SL 1	PABX	IS	DI	AV	N	AV	4
ROLM CBX	PABX	IS	DI	IS	IS	IS	4
STROMBERG-CARLSON Century DCO	CO	IS	IS	IS	AV	IS	16
TRW VIDAR ITS 4, 4/5, 5	TD,CO	AV	IS	AV	N	AV	15
WESCOM 580 DSS	PABX	EI	IS	IS	DI	IS	5

PCM SYSTEMS

Manufacturer/Model	Application	SUBSCRIBER FEATURES							
		Call Transfer, Automatic	Call Diversion	Call Forwarding	Call Conferencing	Camp-On Busy	Call Waiting Indication	Abbreviated Dialing	Universal No. Emgy. Service
CITCOM E10	CO	IS	IS	IS	IS	N	N	IS	N
CITCOM E10	PABX	IS	IS	IS	IS	IS	AV	IS	AV
COLLINS RADIO DTS	TD				IS			IS	
GTE AUTOMATIC ELECTRIC GTD-120	PABX	IS	N	N	IS	IS	N	N	N
NORTH ELECTRIC DSS-1	CO	AV	AV	AV	AV	AV	N	AV	IS
NORTHERN TELECOM SL 1	PABX	AV	AV	AV	AV	AV	AV	AV	AV
ROLM CBX	PABX	IS	IS	IS	IS	IS	IS	IS	N
STROMBERG-CARLSON Century DCO	CO	AV	AV	AV	AV	AV	AV	AV	AV
TRW VIDAR ITS 4, 4/5, 5	TD,CO	AV	N	N	AV	Av	N	AV	AV
WESCOM 580 DSS	PABX	IS	N	IS	IS	IS	IS	IS	IS

PCM SYSTEMS

Manufacturer/Model	Application	SUBSCRIBER FEATURES						
		Malicious Call Identification	Do Not Disturb	Consultation Hold	Absentee Service	Executive Override	Hotline (No. Dialed Conn.)	Attendant Recall (Reminder)
CITCOM E10	CO	IS	N	IS	IS	N	AV	N
CITCOM E10	PABX	IS	AV	IS	N	IS	AV	IS
COLLINS RADIO DTS	TD					IS	IS	
GTE AUTOMATIC ELECTRIC GTD-120	PABX	N	N	IS	IS	N	N	AV
NORTH ELECTRIC DSS-1	CO	IS	N	AV	AV	AV	IS	AV
NORTHERN TELECOM SL 1	PABX	AV	AV	AV	AV	AV	AV	AV
ROLM CBX	PABX	N	IS	IS	N	IS	AV	IS
STROMBERG-CARLSON Century DCO	CO	AV	AV	AV	AV	AV	AV	AV
TRW VIDAR ITS 4, 4/5, 5	TD,CO	AV	N	N	N	N	AV	N
WESCOM 580 DSS	PABX	N	AV	IS	IS	IS	IS	IS

PCM SYSTEMS

Manufacturer/Model	Application	SUBSCRIBER FEATURES: Toll Restriction	Call Splitting By Operator	Direct Inward Dialing (PABX)	Incoming Call Display	Two Party Hold on Console	Attendant Transfer, on all Calls	Line Hunting
CITCOM E10	CO	N	IS	IS	N	IS	AV	Y
CITCOM E10	PABX	IS	IS	IS	IS	IS	IS	IS
COLLINS RADIO DTS	TD	IS		IS		IS		
GTE AUTOMATIC ELECTRIC GTD-120	PABX	IS	AV	N	IS	IS	AV	IS
NORTH ELECTRIC DSS-1	CO	IS	AV	AV	AV	AV	AV	IS
NORTHERN TELECOM SL 1	PABX	AV	AV	AV	AV	AV	AV	AV
ROLM CBX	PABX	IS	IS	IS	IS	IS	IS	IS
STROMBERG-CARLSON Century DCO	CO	AV	AV	AV	AV	AV	AV	AV
TRW VIDAR ITS 4, 4/5, 5	TD,CO	AV	N	AV	N	N	N	N
WESCOM 580 DSS	PABX	IS	IS	IS	IS	IS	IS	IS

PCM SYSTEMS

Manufacturer/Model	Application	SYSTEM FEATURES						
		Intercept	Assigned Night Answer	Identified Outward Dialing	International Direct Dialing	Automatic Number Identification	Automatic Alternative Routing Options	Individua Toll Ticketing
CITCOM E10	CO	N	N	IS	IS	IS	512	IS
CITCOM E10	PABX	IS	IS	IS	IS	IS	256	N
COLLINS RADIO DTS	TD			IS	N		5	
GTE AUTOMATIC ELECTRIC GTD-120	PABX	IS	IS	N	N	N	1	N
NORTH ELECTRIC DSS-1	CO	IS	AV	IS	AV	AV	IS	AV
NORTHERN TELECOM SL 1	PABX	AV	AV	AV	AV	AV	8	AV
ROLM CBX	PABX	IS	IS	IS	IS	N	16	N
STROMBERG-CARLSON Century DCO	CO	AV	AV	AV	AV	AV	Unltd.	AV
TRW VIDAR ITS 4, 4/5, 5	TD,CO	N	N	AV	AV	AV	3	AV
WESCOM 580 DSS	PABX	AV	N	IS	N	IS	2	N

PCM SYSTEMS

Manufacturer/Model	Application	SYSTEM FEATURES: Automatic Message Accounting — Assembled Format	Automatic Message Accounting — Output via Datalink	Reporting--Mode of Communications — Dedicated Channel	CCIS	Modem on Voice Line	System Control and Traffic Administration: Auto. Fault Detection AV	Auto. Fault Detection RE	Auto. Fault Isolation AV	Auto. Fault Isolation RE	Auto. Loop. Test AV	Auto. Loop. Test RE	Auto. Trunk Test AV	Auto. Trunk Test RE
CITCOM E10	CO	IS	IS	IS	IS	IS	Y	Y	Y	Y	Y	Y	Y	Y
CITCOM E10	PABX	IS	IS	IS	IS	IS	Y	Y	Y	Y	Y	Y	Y	Y
COLLINS RADIO DTS	TD						Y	Y	Y	Y	N	N	N	N
GTE AUTOMATIC ELECTRIC GTD-120	PABX	N	N	N	N	N	N	N	N	N	N	N	N	N
NORTH ELECTRIC DSS-1	CO	AV	AV	AV	N	AV	Y	Y	Y	Y	Y	Y	Y	Y
NORTHERN TELECOM SL 1	PABX	AV	AV	AV	N	AV	Y	Y	Y	Y	Y	Y	Y	Y
ROLM CBX	PABX	AV	AV	N	N	IS	Y	Y	Y	Y	N	N	(Y)	(Y)
STROMBERG-CARLSON Century DCO	CO	AV	AV	AV	AV	IS	Y	Y	Y	Y	Y	Y	Y	Y
TRW VIDAR ITS 4, 4/5, 5	TD,CO	AV	AV	AV	N	AV	Y	Y	Y	Y	Y	Y	Y	Y
WESCOM 580 DSS	PABX	N	N	IS	N	IS	Y	Y	Y	Y	N	N	N	N

PCM SYSTEMS

Manufacturer/Model	Application	SYSTEM FEATURES												
		Change of Parameters & Programs		Local Test Desk	100% Traffic Analysis		Full Time Grade-of Service Monitor		Full Time Traffic Statistics		Auto. Line Load Control		Automatic Line Traffic Supervision	
		AV	RE	AV	AV	RE	AV	RE	AV	RE	AV	RE	AV	RE
CITCOM E10	CO	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
CITCOM E10	PABX	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
COLLINS RADIO DTS	TD	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y
GTE AUTOMATIC ELECTRIC GTD-120	PABX	Y	N	N	N	N	N	N	N	N	N	N	N	N
NORTH ELECTRIC DSS-1	CO	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
NORTHERN TELECOM SL 1	PABX	Y	Y	N	Y	Y	N	N	Y	Y	N	N	N	N
ROLM CBX	PABX	Y	Y	Y	N	N	N	N	Y	Y	N	N	N	N
STROMBERG-CARLSON Century DCO	CO	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
TRW VIDAR ITS 4, 4/5, 5	TD,CO	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
WESCOM 580 DSS	PABX	Y	Y	Y	Y	Y	N	N	Y	Y	N	N	N	N

PCM SYSTEMS

		DIGITAL SYSTEMS							
						Main PCM Highways		Compatibility of Trunks	
Manufacturer/Model	Application	Matrix Type	SPC Control of Remote Concentrators	SPC Control of Remote Office	SPC Control of Analog & Digital Matrix	Bit Serial Speed (Mbps)	Bits in Parallel	30 Channel PCM (CEPT)	24 Channel PCM (T1)
CITCOM E10	CO	TST	Y	Y	N	4		Y	Y
CITCOM E10	PABX	T	Y	Y	N	8		Y	N
COLLINS RADIO DTS	TD	TST	N	N	N	3.072	1	N	Y
GTE AUTOMATIC ELECTRIC GTD-120	PABX		N	N	N	1.536		N	Y
NORTH ELECTRIC DSS-1	CO	TST	Y	Y	N	2.048	8	N	Y
NORTHERN TELECOM SL 1	PABX	T	Y	Y	N	2		(Y)	Y
ROLM CBX	PABX	T	N	N	N	4.608	12	N	N
STROMBERG-CARLSON Century DCO	CO	TST	Y	Y	Y	8.192	1	Y	Y
TRW VIDAR ITS 4, 4/5, 5	TD,CO	TST	Y	Y	N	3.088	9	N	Y
WESCOM 580 DSS	PABX	T	Y	N	N	1.544	10	N	Y

PCM SYSTEMS

Manufacturer/Model	Application	DIGITAL SYSTEMS SUBSCRIBER INTERFACE						
		Compatibility of Trunks		Concentrator Stage		CODEC		
		Analog u-Law Encoding	Analog A-Law Encoding	Space Division	Time Division	μ-Law	A-Law	No. of Lines per CODEC
CITCOM E10	CO	Y	Y	Y	N	Y	Y	30
CITCOM E10	PABX	N	Y	Y	N	Y	Y	30
COLLINS RADIO DTS	TD	Y	N	N	N	NA	NA	NA
GTE AUTOMATIC ELECTRIC GTD-120	PABX	Y	N	Y	N	Y	N	40/24
NORTH ELECTRIC DSS-1	CO	Y	N	N	Y	Y	N	1
NORTHERN TELECOM SL 1	PABX	Y	(Y)	N	Y	Y	(Y)	1
ROLM CBX	PABX	Analog,	Linear	N	Y	Linear	Law	16
STROMBERG-CARLSON Century DCO	CO	Y	Y	N	Y	Y	Y	1
TRW VIDAR ITS 4, 4/5, 5	TD,CO	Y	N	N	Y	Y	N	24
WESCOM 580 DSS	PABX	Y	N	N	Y	Y	N	24

PCM SYSTEMS

Manufacturer/Model	Application	SUBSCRIBER LINE INTERFACE						
		Hybrid					Adjustable Gain	
		Type	Adjustable	Manually Adjusted	Adjusted Under SPC	Self-Adjust	Adjustable	Manually Adjusted
CITCOM E10	CO	Active	Y	Y	N	N	Y	Y
CITCOM E10	PABX	Active	Y	Y	N	N	Y	Y
COLLINS RADIO DTS	TD	NA	NA	NA	NA	NA	NA	NA
GTE AUTOMATIC ELECTRIC GTD-120	PABX	Solid State	N	N	N	N	Y	Y
NORTH ELECTRIC DSS-1	CO	Active	N	N	N	N	N	N
NORTHERN TELECOM SL 1	PABX	CMOS	N	N	N	N	Y	N
ROLM CBX	PABX	Transformer	N	N	N	N	Y	N
STROMBERG-CARLSON Century DCO	CO	Passive	Y	Y	N	N	N	N
TRW VIDAR ITS 4, 4/5, 5	TD,CO	Transformer	Y	Y	N	N	Y	Y
WESCOM 580 DSS	PABX	Active	N	N	N	N	Y	N

PCM SYSTEMS

Manufacturer/Model	Application	SUBSCRIBER LINE INTERFACE				
		Gain	Ring	Test		
		Adjusted Under SPC	Applied Through:	Metallic Access	Non-metallic Access	Time Sequenced Test
CITCOM E10	CO	N	Relay	Y	N	Y
CITCOM E10	PABX	N	Relay	Y	N	Y
COLLINS RADIO DTS	TD	NA	NA	NA	NA	NA
GTE AUTOMATIC ELECTRIC GTD-120	PABX	N	Relay	Y	N	N
NORTH ELECTRIC DSS-1	CO	N	Relay			
NORTHERN TELECOM SL 1	PABX	Y	Relay	Y	N	Y
ROLM CBX	PABX	Y	Relay	N	N	N
STROMBERG-CARLSON Century DCO	CO	N	Relay	Y	N	Y
TRW VIDAR ITS 4, 4/5, 5	TD,CO	Y	Relay	Y	N	Y
WESCOM 580 DSS	PABX	Y	Relay	N	N	N

SUMMARIZATION OF SOLID STATE ANALOG,
PAM AND PWM MATRICES
Offered by Manufacturers

Manufacturer/Model	Application	Traffic Capacity (Erlangs) Max.	Min.	Economic Size-Lines or Trunks Max.	Min.	Engineered Traffic per Line or Trunk (Erlangs) Max.	Min.	Busy Hour Calls (000's) Max.	Min.	Busy Hour Call Attempts (000's) Max.	Min.	Assumed Average Holding Time (Seconds)
SOLID STATE ANALOG												
GTE SYLVANIA ETSS	TD	1275	91	1536T	96T	0.95 (T)	0.83 (T)	19.125	1.365	22.95	1.7	240
HITACHI EX 10	PABX	157.6	39.4	1024 (L)	100L	0.408 (L)	0.154 (L)	5.2	5.2	6.0	6.0	180/300
ITT T6S2, TCS5	PABX CO	1400		12000L	600L			50	50			
SIEMENS SD-192	PABX	36		192L	48L	0.22	1.0					
PAM MATRIX												
WESTERN ELECTRIC DIMENSION 400	PABX			400								
WESTERN ELECTRIC DIMENSION 2000	PABX			2000 (5000)								
T & N 6030 E	PABX	87		100L 10T	800L 80T	.17	.17			10	10	150
T & N 6030 z	PABX	470	172	1000L 100T	3000L 500T	.15	.15			40	40	150
PWM MATRIX												
CHESTEL BCS 250	PABX			1000L	100L	.25	1.0					
DANRAY CBX/CTSS	PABX TD	500 (4000)		8000L 1000L	500L 100T	00.21 T.1	L10 T.1	32	8	60	15	240

Manufacturer/Model	Application	Internal Call Loss Probability (Percent)	Matrix is Non-blocking	No. of Lines or Trunks Per Matrix Module	Multi-processor	Operating Temperature (°C) From	Operating Temperature (°C) To	Range of Humidity (Percent) From	Range of Humidity (Percent) To
SOLID STATE ANALOG									
GTE SYLVANIA ETSS	TD	1.0	(Y)	96 T	N	10	50	20	95
HITACHI EX 10	PABX	1.0	N	56 L 32 T	N	5	40	20	80
ITT TCS2, TCS5	PABX CO		N	30 L	N	5	32	20	80
SIEMENS SD-192	PABX		N		N	0	50	20	90
PAM MATRIX									
WESTERN ELECTRIC DIMENSION 400	PABX								
WESTERN ELECTRIC DIMENSION 2000	PABX								
T & N 6030 E	PABX	1.0	N		N	0	40	30	75
T & N 6030 Z	PABX	0.6	N		N	0	40	30	75
PWM MATRIX									
CHESTEL BCS 250	PABX	1.0	N		N	0	55	0	95
DANRAY CBX/CTSS	PABX TD		Y (TD)			5	26	10	80

Manufacturer/Model	Application	Fan Required: Entire Switch	Fan Required: Common Control	Air Conditioning Required	Fungus Protection	Dust Protection	Power Consumption: Busy Hour (KW)	Power Consumption: Slack Hour (KW)	Voltage and Range: From	Voltage and Range: To
SOLID STATE ANALOG										
GTE SYLVANIA ETSS	TD	Y	Y	N	N	N	14.3	14.3	105/115 210/230	
HITACHI EX 10	PABX	N	Y	Y	Y	Y	5.3 (1000 Lines)	1.4 (1000 Lines)	110AV /48DC	
ITT TCS2, TCS5	PABX CO			Y					50DC	44/ 56
SIEMENS SD-192	PABX	N	N	N	N	Y	0.9	0.35	115AC	85/ 130
PAM MATRIX										
WESTERN ELECTRIC DIMENSION 400	PABX						0.5	0.325	120AC	99/ 129
WESTERN ELECTRIC DIMENSION 2000	PABX						4.1 (1000 Lines)	2.8 (1000 Lines)	120V	102/ 13
T & N 6030 E	PABX	N	Y	N	Y	N	7.5	6.0	48VDC	43/ 57
T & N 6030 Z	PABX	N	Y	N	Y	N	7.5 (1000 Lines)	6.0 (1000 Lines)	48VDC	43/ 57.5
PWM MATRIX										
CHESTEL BCS 256	PABX	N	N	N	N	N	.7	.7	115AC	230AC +15%
DANRAY CBX/CTSS	PABX TD	N	Y	Y	N	Y	100 (1000 Lines)	(1000 Lines)	203/120	210%

Manufacturer/Model	Appli-cation	Reliability: Year per 1 hour of Downtime	Reliability: MTBF (Hours)	Reliability: MTTR (Hours)	Installation Factors: Frame Height (mm)	Installation Factors: Average Floor Loading (Kg/m^2)	Configuration: Max. (Lines) (per m^2)	Configuration: Min. (Lines) (per m^2)	Fully Connectorized
SOLID STATE ANALOG									
GTE SYLVANIA ETSS	TD	2	38	.33	2100	490	118	39	Y
HITACHI EX 10	PABX	10	14	0.16	1960	500	116	177	Y
ITT TCS2, TCS5	PABX CO				1981	500	172	70	Y
SIEMENS SD-192	PABX				1975	290	423	106	Y
PAM MATRIX									
WESTERN ELECTRIC DIMENSION 400	PABX				1765	690	58	58	Y
WESTERN ELECTRIC DIMENSION 2000	PABX				a:1765 b:2210	735	33 (66)	36	Y
T & N 6030 E	PABX				2280	500	10	33	Y
T & N 6030 Z	PABX	10			a:2000 b:2250	500	42	50	Y
PWM MATRIX									
CHESTEL BCS 256	PABX				2134				Y
DANRAY CBX/CTSS	PABX TD	7	8000	0.25	1982	200	76	38	Y

Manufacturer/Model	Application	Subscriber Line Interface: Analog 2-wire	Analog 4-wire	Maximum Loop Resist (Ohms)	Echo Return Loss (db)	Singing Margin (db)	CVSD	CVSD Bit Rate (Kbps)
SOLID STATE ANALOG								
GTE SYLVANIA ETSS	TD	NA	NA	NA	NA		N	
HITACHI EX 10	PABX	Y	N	1000			N	
ITT TCS2, TCS5	PABX CO	Y	N	1900			N	
SIEMENS SD-192	PABX	Y	(Y)	1200	12	14	N	
PAM MATRIX								
WESTERN ELECTRIC DIMENSION 400	PABX	Y	N				N	
WESTERN ELECTRIC DIMENSION 2000	PABX	Y	N				N	
T & N 6030 E	PABX	Y	N	720	20	10	N	
T & N 6030 Z	PABX	Y	N	880	20	10	N	
PWM MATRIX								
CHESTEL BCS 256	PABX	Y	Y	1300			Y	31.5 or 16
DANRAY CBX/CTSS	PABX TD	Y	Y	1300	26	26	Y	Up to 64

Manufacturer/Model	Application	Trunk Line Interfaces: Analog 2-wire	Analog 4-wire	CVSD	CVSD Multiplex	CVSD Bit Rate (Kpbs)	PCM Multiplex	PCM Bit Rate (Kpbs)
SOLID STATE ANALOG								
GTE SYLVANIA ETSS	TD	Y	Y	N	N	------	N	------
HITACHI EX 10	PABX	Y	N	N	N	------	N	------
ITT TCS2, TCS5	PABX CO	Y	Y	N	N	------	N	------
SIEMENS SD-192	PABX	Y	(Y)	N	N	------	N	------
PAM MATRIX		Y	Y	N	N	------	N	------
WESTERN ELECTRIC DIMENSION 400	PABX							
WESTERN ELECTRIC DIMENSION 2000	PABX	Y	Y	N	N	------	N	------
T & N 6030 E	PABX	Y	Y	N	N	------	N	------
T & N 6030 Z	PABX	Y	Y	N	N	------	Y	2048 (CEPT)
PWM MATRIX								
CHESTEL BCS 256	PABX	Y	Y	N	N	------	Y	1544 (T1)
DANRAY CBX/CTSS	PABX TD	Y	Y	Y	N	------	N	------

Manufacturer/Model	Application	Transmission Characteristic Analog, Intraoffice: Frequency Response (Hz) From	To	Maximum Data Rate with Modem (Bits/Second)	Net Loss (db)	Digital: Direct Digital Data Rate (Kbps)	Components, Duplicated for Reliability: Common Control	Matrix	SLU	Manual Patch-Through Possible
SOLID STATE ANALOG										
GTE SYLVANIA ETSS	TD	300	108	50K	0.5					
HITACHI EX 10	PABX	200	3400	2400	2.8		Y (2)	N	N	Y
ITT TCS2, TCS5	PABX CO						N	(N)	N	Y
SIEMENS SD-192	PABX	200	3400	9600	4,L-L .7,L-T					Y
PAM MATRIX										
WESTERN ELECTRIC DIMENSION 400	PABX						N	N	N	Y
WESTERN ELECTRIC DIMENSION 2000	PABX						N	N	N	N
T & N 6030 E	PABX	300	3400	9600	1.0		Y (2)	N	N	N
T & N 6030 Z	PABX	300	3400	9600	1.0		N	N	N	N
PWM MATRIX										
CHESTEL BCS 256	PABX	300	3400	9600	var.		Y (2)	Y	Y	N
DANRAY CBX/CTSS	PABX TD	300	3300	9600	0.0	64	Y	Y	N	Y

Manufacturer/Model	Application	Signalling and Supervision: Local						Interoffice						
		DC Dial Pulse	Touch Tone	DC Neon Dial	AC Dialing	VF 2280Hz	VF 600/750Hz	CX	DX	Decadic	E&M	Loop	MF	MFC
SOLID STATE ANALOG														
GTE SYLVANIA ETSS	TD	Y	Y	N	Y	N	N	Y	Y	Y	Y	Y	Y	Y
HITACHI EX 10	PABX	Y	Y	(Y)	(Y)	(Y)	(Y)	N	Y	Y	Y	Y	Y	Y
ITT TCS2, TCS5	PABX CO	Y	Y	N	N	N	N			Y	Y	Y	N	Y
SIEMENS SD-192	PABX	Y	Y	N	N	N	N	N	N	N	Y	Y	N	N
PAM MATRIX														
WESTERN ELECTRIC DIMENSION 400	PABX	Y	Y	N	N	N	N	Y	Y	Y	Y	Y	Y	N
WESTERN ELECTRIC DIMENSION 2000	PABX	Y	Y	N	N	N	N	Y	Y	Y	Y	Y	Y	N
T & N 6030 E	PABX	Y	Y	N	N	N	N			Y	Y	Y	Y	Y
T & N 6030 Z	PABX	Y	Y	(Y)	N	N	N			Y	Y	Y	Y	Y
PWM MATRIX														
CHESTEL BCS 256	PABX	Y	Y	N	N	N	N	Y	Y	N	Y	Y	Y	N
DANRAY CBX/CTSS	PABX TD	Y	Y	Y	Y	N	N	N	N	N	Y	Y	Y	N

Manufacturer/Model	Application	Signalling and Supervision Interoffice: SF-2600Hz	CCITT #4	CCITT #5	CCITT #6	CCITT #7	PCM T1	PCM CEPT	Other	Interface With Other Systems: AUTOVON	NATO	AN/TTC38
SOLID STATE ANALOG												
GTE SYLVANIA ETSS	TD	Y	Y	Y	N	N	N	N		Y	Y	Y
HITACHI EX 10	PABX	N	N	N	N	N	N	N		N	N	N
ITT TCS2, TCS5	PABX CO				N	N	N	N				
SIEMENS SD-192	PABX	N	(N)	(N)	N	N	N	N		N	N	N
PAM MATRIX												
WESTERN ELECTRIC DIMENSION 400	PABX	Y	N	N	N	N	N	N		Y	Y	Y
WESTERN ELECTRIC DIMENSION 2000	PABX	Y	N	N	N	N	N	N		Y	Y	Y
T & N 6030 E	PABX	N	N	N	N	N	N	N		N	N	N
T & N 6030 Z	PABX	N	N	N	N	N	N	Y		N	N	N
PWM MATRIX												
CHESTEL BCS 256	PABX	N	N	N	N	N	N	N		N	N	N
DANRAY CBX/CTSS	PABX TD	Y	Y	Y	Y	N	N	N		Y	N	N

Manufacturer/Model	Application	AN/TTC39	Germany	France	Belgium	Holland
		Interface With Other Systems				
SOLID STATE ANALOG						
GTE SYLVANIA ETSS	TD	Y	Y	Y	Y	Y
HITACHI EX 10	PABX	N	N	N	N	N
ITT TCS2, TCS5	PABX CO					
SIEMENS SD-192	PABX	N	(Y)	(Y)	(Y)	(Y)
PAM MATRIX						
WESTERN ELECTRIC DIMENSION 400	PABX	Y	Y	Y	Y	Y
WESTERN ELECTRIC DIMENSION 2000	PABX	Y	Y	Y	Y	Y
T & N 6030 E	PABX	N	Y	N	Y	Y
T & N 6030 Z	PABX	N	Y	N	Y	Y
PWM MATRIX						
CHESTEL BCS 256	PABX	N	N	N	N	N
DANRAY CBX/CTSS	PABX TD	N	N	N	N	N

Manufacturer/Model	Application	Military System Features					
		Five Levels of Precedence Service	Fixed Directory Translator Table	Conference			Secure Call Mode/Key Conversion
				Progressive	Preprogrammed	Conference Broadcast	
SOLID STATE ANALOG							
GTE SYLVANIA ETSS	TD	IS	IS	IS	IS	AV	AV
HITACHI EX 10	PABX	EI	EI	IS	EI	EI	N
ITT TCS2, TCS5	PABX CO						
SIEMENS SD-192	PABX	EI	EI	EI	EI	EI	DI
PAM MATRIX							
WESTERN ELECTRIC DIMENSION 400	PABX	IS	DI	DI	EI	EI	DI
WESTERN ELECTRIC DIMENSION 2000	PABX	IS	DI	DI	EI	EI	DI
T & N 6030 E	PABX	DI	EI	EI	EI	EI	DI
T & N 6030 Z	PABX	DI	EI	EI	EI	EI	DI
PWM MATRIX							
CHESTEL BCS 256	PABX	EI	EI	IS	EI	EI	DI
DANRAY CBX/CTSS	PABX TD	IS	IS	IS	EI	EI	EI

Manufacturer/Model	Application	Military System Features				Numbering Plan	
		Direct Access Service	Up to 100 Class-of-Service Marks	Zone Restrictions	Circuit Switching of Data	Unrestricted Numbering	Max No. of Digits
SOLID STATE ANALOG							
GTE SYLVANIA ETSS	TD	IS	IS	IS	AV	IS	13
HITACHI EX 10	PABX	EI	AV	AV	EI	AV	5
ITT TCS2, TCS5	PABX CO		AV	AV			
SIEMENS SD-192	PABX	EI	DI	EI	EI	IS	3
PAM MATRIX							
WESTERN ELECTRIC DIMENSION 400	PABX	EI	DI	DI	DI	IS	4
WESTERN ELECTRIC DIMENSION 2000	PABX	EI	DI	DI	DI	IS	4
T & N 6030 E	PABX	IS	IS	IS	AV	EI	4
T & N 6030 Z	PABX	IS	IS	IS	AV	IS	4(5)
PWM MATRIX							
CHESTEL BCS 256	PABX	EI	EI	IS	EI	AV	5
DANRAY CBX/CTSS	PABX TD	IS	IS	IS	IS	IS	20

		SUBSCRIBER FEATURES							
Manufacturer/Model	Application	Call Transfer, Automatic	Call Diversion	Call Forwarding	Call Conferencing	Camp-On Busy	Call Waiting Indication	Abbreviated Dialing	Universal No. Emgy. Service
SOLID STATE ANALOG									
GTE SYLVANIA ETSS	TD	IS	IS	AV	IS	IS	AV	IS	AV
HITACHI EX 10	PABX	IS	IS	IS	IS	IS	IS	IS	AV
ITT TCS2, TCS5	PABX CO	IS	AV	IS	IS	IS	IS	IS	IS
SIEMENS SD-192	PABX	IS	N	IS	IS	IS	IS	N	N
PAM MATRIX									
WESTERN ELECTRIC DIMENSION 400	PABX	IS	IS	IS	IS	IS	IS	IS	N
WESTERN ELECTRIC DIMENSION 2000	PABX	IS	IS	IS	IS	IS	IS	IS	N
T & N 6030 E	PABX	IS	IS	IS	N	IS	IS	IS	N
T & N 6030 Z	PABX	IS	IS	IS	N	IS	IS	IS	AV
PWM MATRIX									
CHESTEL BCS 256	PABX	IS	IS	IS	IS	IS	IS	IS	IS
DANRAY CBX/CTSS	PABX TD	IS	IS	IS	IS	IS	IS	IS	N

Manufacturer/Model	Application	SUBSCRIBER FEATURES						
		Malicious Call Identification	Do Not Disturb	Consultation Hold	Absentee Service	Executive Override	Hotline (No. Dialed Conn.)	Attendant Recall (Reminder)
SOLID STATE ANALOG								
GTE SYLVANIA ETSS	TD	AV	IS	IS	IS	IS	IS	AV
HITACHI EX 10	PABX	N	IS	IS	IS	IS	IS	IS
ITT TCS2, TCS5	PABX CO	IS	IS	IS	IS	N	IS	IS
SIEMENS SD-192	PABX	N	N	IS	IS	IS	N	IS
PAM MATRIX								
WESTERN ELECTRIC DIMENSION 400	PABX	N	N	IS	IS	IS	IS	IS
WESTERN ELECTRIC DIMENSION 2000	PABX	N	N	IS	IS	IS	IS	IS
T & N 6030 E	PABX	IS	IS	IS	IS	IS	AV	IS
T & N 6030 Z	PABX	IS	IS	IS	IS	IS	IS	IS
PWM MATRIX								
CHESTEL BCS 256	PABX	AV	IS	IS	IS	IS	IS	IS
DANRAY CBX/CTSS	PABX TD	N	IS	IS	IS	IS	IS	IS

Manufacturer/Model	Application	SUBSCRIBER FEATURES						
		Toll Restriction	Call Splitting By Operator	Direct Inward Dialing (PABX)	Incoming Call Display	Two Party Hold on Console	Attendant Transfer, on all Calls	Line Hunting
SOLID STATE ANALOG								
GTE SYLVANIA ETSS	TD	IS	IS	IS	AV	IS	IS	IS
HITACHI EX 10	PABX	IS	IS	AV	IS	IS	IS	IS
ITT TCS2, TCS5	PABX CO	IS	IS	IS	IS	IS	IS	IS
SIEMENS SD-192	PABX	IS	IS	AV	IS	N	IS	IS
PAM MATRIX								
WESTERN ELECTRIC DIMENSION 400	PABX	IS	IS	IS	IS	IS	IS	IS
WESTERN ELECTRIC DIMENSION 2000	PABX	IS	IS	IS	IS	IS	IS	IS
T & N 6030 E	PABX	IS	N	IS	IS	IS	IS	IS
T & N 6030 Z	PABX	IS	N	IS	IS	IS	IS	IS
PWM MATRIX								
CHESTEL RCS 256	PABX	IS	IS	IS	AV	IS	IS	IS
DANRAY CBX/CTSS	PABX TD	IS	IS	IS	IS	IS	IS	IS

Manufacturer/Model	Application	SYSTEM FEATURES Intercept	Assigned Night Answer	Identified Outward Dialing	International Direct Dialing	Automatic Number Identification	Automatic Alternative Routing Options	Individua Toll Ticketing
SOLID STATE ANALOG								
GTE SYLVANIA ETSS	TD	IS	IS	IS	IS	AV	4	AV
HITACHI EX 10	PABX	IS	IS	AV	IS	AV	un-limited	AV
ITT TCS2, TCS5	PABX CO	IS	IS	IS	AV	IS	AV	IS
SIEMENS SD-192	PABX	IS	IS	N	IS	N	3	N
PAM MATRIX								
WESTERN ELECTRIC DIMENSION 400	PABX	IS	IS	IS	IS	IS	4	N
WESTERN ELECTRIC DIMENSION 2000	PABX	IS	IS	IS	IS	IS	4	N
T & N 6030 E	PABX	IS	IS	N	AV	N	3	IS
T & N 6030 Z	PABX	IS	IS	N	IS	N	3	IS
PWM MATRIX								
CHESTEL BCS 256	PABX	IS	IS	AV	AV	AV	un-limited	AV
DANRAY CBX/CTSS	PABX TD	IS	IS	IS	IS	IS	5	IS

Manufacturer/Model	Application	SYSTEM FEATURES: Automatic Message Accounting: Assembled Format	Automatic Message Accounting: Output via Datalink	Reporting--Mode of Communications: Dedicated Channel	Reporting--Mode of Communications: CCIS	Reporting--Mode of Communications: Modem on Voice Line	System Control and Traffic Administration: Auto. Fault Detection AV	Auto. Fault Detection RE	Auto. Fault Isolation AV	Auto. Fault Isolation RE	Auto. Loop. Test AV	Auto. Loop. Test RE	Auto. Trunk Test AV	Auto. Trunk Test RE
SOLID STATE ANALOG														
GTE SYLVANIA ETSS	TD	IS	AV	AV	IS	AV	Y	Y	Y	Y	Y	Y	Y	Y
HITACHI EX 10	PABX	AV	AV	AV	N	AV	Y	Y	Y	Y	Y	Y	N	N
ITT TCS2, TCS5	PABX CO	IS	IS	IS	N	AV	Y	Y	Y	Y	Y	Y	Y	Y
SIEMENS SD-192	PABX	AV	N	IS	N	IS	Y	Y	Y	Y	N	N	N	N
PAM MATRIX														
WESTERN ELECTRIC DIMENSION 400	PABX	N	N	IS	N	IS	Y	Y	Y	Y	N	N	N	N
WESTERN ELECTRIC DIMENSION 2000	PABX	N	N	IS	N	IS	Y	Y	Y	Y	N	N	N	N
T & N 6030 E	PABX	IS	N	N	N	N	Y	N	N	N	N	N	N	N
T & N 6030 Z	PABX	IS	N	N	N	N	Y	N	Y	N	N	N	N	N
PWM MATRIX														
CHESTEL BCS 256	PABX	IS	IS	IS	N	IS	Y	Y	Y	Y	N	N	N	N
DANRAY CBX/CTSS	PABX TD	IS	IS	IS	N	AV	Y	Y	Y	Y	Y	N	Y	Y

Manufacturer/Model	Application	SYSTEM FEATURES												
		Change of Parameters & Programs		Local Test Desk	100% Traffic Analysis		Full Time Grade-of Service Monitor		Full Time Traffic Statistics		Auto. Line Load Control		Automatic Line Traffic Supervision	
		AV	RE	AV	AV	RE	AV	RE	AV	RE	AV	RE	AV	RE
SOLID STATE ANALOG														
GTE SYLVANIA ETSS	TD	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
HITACHI EX 10	PABX	Y	Y	Y	Y	Y	N	N	Y	Y	N	N	N	N
ITT TCS2, TCS5	PABX CO	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y
SIEMENS SD-192	PABX	Y	Y	N	N	Y	Y	N	N	N	N	N	N	N
PAM MATRIX														
WESTERN ELECTRIC DIMENSION 400	PABX	Y	Y	N	Y	Y	N	N	N	N	N	N	N	N
WESTERN ELECTRIC DIMENSION 2000	PABX	Y	Y	N	Y	Y	N	N	N	N	N	N	N	N
T & N 6030 E	PABX	Y	N	Y	Y	N	N	N	N	N	N	N	N	N
T & N 6030 Z	PABX	Y	N	Y	Y	N	N	N	N	N	N	N	N	N
PWM MATRIX														
CHESTEL BCS 256	PABX	Y	Y	Y	Y	Y								
DANRAY CBX/CTSS	PABX TD	Y	Y	N	Y	Y	N	N	Y	Y	Y	Y	N	N

C. DETAILED RESULTS FOR REPRESENTATIVE SYSTEMS

The remainder of this chapter is devoted to detailed system descriptions for which we were able to obtain information. The manufacturer, type of equipment, intended application, technology type, and size range are summarized at the top of the page. Basically, the format of the system descriptions is as follows:

- Switching Network
- Attendant Console
- Features
- Features of Special Interest
- Circuit Switching of Data
- System Advantages
- System Disadvantages

CHESTEL

MANUFACTURER:	CHESTEL, Inc., Chester, Connecticut
TYPE:	BCS 256
APPLICATION:	PABX
TECHNOLOGY:	Pulse Width Modulation, Time-Division-Multiplexed
SIZE RANGE:	100 to 1,000 Lines and Trunks Combined

This is a new product, based on the technology of the same firm's existing product, a 50-line PABX. It is scheduled to be available in the first half of 1978.

Switching Network

The basic switch consists of a nonblocking matrix and a common control housed together in one cabinet. The matrix has 256 ports in its maximum configuration, each of which accepts either a subscriber line or a trunk, or a data interface for digital data of 15.6 Kbps. Up to 1,000 ports become available, if four fully configured, nonblocking matrices are interconnected. The resulting network is no longer nonblocking. The exact traffic carrying capability depends on the number and type of interconnecting paths. Only one common control is used for up to four basic matrices.

The switch uses pulse width modulation (PWM) in combination with time division multiplexed switching. The matrix is of the four-wire type, requiring each trunk or line interface to contain a hybrid circuit. Trunk and line interfaces also contain a PWM modulator and demodulator each. Pulse width is in the submicrosecond range, allowing the multiplexing of all 256 lines of the basic matrix into one time-slot each and still use a relatively high sampling rate of 15.6 KHz (as far as we could learn). This sampling rate, which is about twice as high as the rate of eight KHz found in PCM systems, helps to simplify the design specifications for the analog transmit and receive filters in the line interfaces, thus reducing the cost of this part of the system.

It should be noted, that the time division switching scheme requires each PWM modulator to be synchronized with the internal clock.

No redundancy increasing design measures are incorporated into this switching matrix.

Interfaces for two- and four-wire trunks, two- and four-wire subscriber loops, interfaces for digital data lines and PCM multiplexed trunks (T1 format) are available. Otherwise, all ports on the switching network are alike in traffic capacity and are interchangeable.

<u>Common Control</u>

The common control uses a single CPU (not duplicated). Not much more could be learned about this part of the system.

<u>Attendant Console</u>

Status of all lines and trunks displayed. Direct addressing of all trunks.

<u>Features:</u>

Those listed in summary tables plus several more.

<u>Features of Particular Interest</u>

- o Nonblocking matrix for systems with up to 255 ports.
- o Interfaces with PCM multiplexed T1 lines.
- o Accepts two- and four-wire station loops, as well as two- and four-wire trunks.
- o Circuit switching of data.
- o Accepts CCIS according to CCITT #6 specifications.
- o Wide range of conferencing modes.

<u>Circuit Switching of Data</u>

Normal line circuits will allow modem signals to pass through the switch up to 9600 bits/second. Special interface to port for direct transmission of digital data at 15.6 Kbps or, multiplexed into two ports, at 31.5 Kbps. It is feasible to transmit 64 Kbps through four ports although such an interface does not seem to exist yet.

System Advantages

- Offers all PABX subscriber features from our questionnaire, except automatic line and trunk testing.
- Allows four-wire station loops.
- Allows circuit switching of data.
- Available in a wide range of system sizes.
- Offers progressive, pre-programmed and broadcast conferencing.
- More than five levels of precedence (override) mode.
- More than 100 class of service marks.

System Disadvantages

- New system, no reliability information available.
- Unusual technology, only system of this kind.
- Data speeds which are not divisible by 64,000 are not so easily accommodated.
- Data which are directly transmitted through the switch are not compatible with PCM multiplexed (T1 type) trunk interface.

COLLINS

MANUFACTURER: Collins Radio Group, Dallas, Texas

TYPE: DTS System

APPLICATION: Tandem

TECHNOLOGY: PCM Time Division

SIZE RANGE: Up to 1424 Trunks

The COLLINS DTS (Digital Tandem Switch) has been designed to meet the needs for a tandem switch in private corporate networks. Subsequently, a toll/tandem version and an automatic call distribution system, mainly for airline reservation applications, were developed. Of particular interest is the version of this switch which is used in the Royal Netherlands Air Force Automatic Switched Communication Network (ASCON). The ASCON system, which was built by COLLINS, is an integrated transmission and switching network, covering all of Holland and using the North American (T1) PCM standard. Main transmission links are by digital microwave, switching uses the DTS with special military software enhancements. The information in our summary tables reflects both the capabilities of the basic DTS as well as some of the ASCOM enhancements. It further lists some of the features available with a special PABX package. This package is intended for applications where local lines (PABX) are to be connected to a tandem switch in a private network. Hardware wise, these local lines are implemented with PCM channel banks, connecting 24 local lines to one T1 port. Thus, any number of lines with one Erlang of capacity each can be connected.

Switching Network

The switching network is of the time-space-time type. Up to 60 matrix modules contain an incoming and an outgoing time switch (time-slot interchange) each, plus the associated portion of the time-multiplexed space switch and the control stores. Each time-switch accepts one multiplexed trunk group of the T1 (24 channel) format, and allows a change in the sequence of the incoming T1 frame into any other sequence The same function is performed on the outgoing part of the T1 multiplex. The space switch is of the fully available, 60 by 60 configuration, thus making the complete network

nonblocking up to its maximum size of 24 times 60, or 1,440 trunks Maximum practical size is 1,424 trunks, which allows a number of trunks for administrative and test purposes.

The matrix may be expanded in increments of one module, which will accept one additional T1 line with 24 channels. Five standard configurations of the system are offered, with maximum sizes of 288, 576, 864, 1,152, and 1,440 trunks. Each of these configurations may be expanded into the next larger one.

Analog trunks as well as two- and four-wire subscriber lines are connected with the digital network via standard channel bank equipment. Channel banks offered by COLLINS with their switch are manufactured by ITT.

The switching network, or parts of it, are not duplicated for redundancy.

Common Control

The common control uses a commercial minicomputer, the DEC PDP 11/35. Two processors are combined in a redundant configuration. Additional programs and tables are stored on a "hard" disk. With this processing capability, functions which are needed in addition to the switching program are easily implemented, for example, call distribution software, PABX functions and military network control functions (in the ASCON system).

A variety of peripherals are available for system control, as well as input/output for various additional functions.

Features

As listed in the summary table, the software package developed for ASCON contains a full set of military system features: precedence service, all three modes of conferencing, tables and other provisions for connection of "roving subscribers" and additional routing capabilities. It should be noted, however, that conferencing is only possible within a PCM encoded group of subscribers.

Features of Special Interest:

- o Normal switch has a "surplus" of processing capability, applicable to additional special programs.
- o Special features for military applications available in the ASCON system package.
- o "T1 by-pass" switch available (from ASCON). In an integrated switching and transmission environment, this switch allows direct connection of certain incoming and outgoing T1 lines in order to by-pass an inoperative switch.
- o For circuit switching of data and CVSD see next heading.

Circuit Switching of Data

COLLINS has developed an interface to allow transmission of digital data through the switch. This interface, apparently of a configuration similar to that of the common channel bank equipment, allows multiplexing (and demultiplexing of) 24 individual channels of 64 Kbps each into the standard T1/D2 format. Digital data uses diphase line mode on four-wire circuits. On these lines, the 64 Kbps are embedded into a 72 Kbps frame format. The additional bits are stripped off at the multiplexing interface.

Application of this interface is for connection of PCM type digital telephones, as well as for data transmission. NOTE: Whenever the standard T1/D2 format is used, data transmission is restricted to 56 Kbps maximum, since the eighth bit of the PCM word is not fully available for data.

Analog telephones may be connected to this interface by substituting a special circuit card for each channel to be used this way.

COLLINS seems to be in a position to accept orders on this interface.

COLLINS also seems to be in the process of designing a special interface to send 16 Kbps CVSD over the PCM switch, obviously on special order from a customer.

System Advantages

- This is the first digital switch installed in regular service in the U.S. (according to COLLINS), therefore, quite some operational experience is available.
- Experience from ASCON is very useful and a software package from ASCOM is available.
- Tl by-pass switch available (see special features).

System Disadvantages

- Matrix or parts of it not duplicated for redundancy (single failures, however, can only affect 24 trunks).
- Does not interface with European (CEPT) PCM standard.

CIT-ALCATEL

MANUFACTURER:	CIT-ALCATEL, Paris, France
TYPE:	E 10
APPLICATION:	Class 5, PABX
TECHNOLOGY:	PCM Time Division
SIZE RANGE:	C.O.: 2,000 to 30,000 Lines PABX: 1,000 to 15,000 Lines

The E-10 has been the first PCM local switch in the world which was used in regular service in a public telephone network. Originally, the E-10 was designed with a capacity of 1,300 Erlangs and was intended for application in rural areas. Later, the switch has been upgraded to more than twice this capacity and is now even used in clusters to serve areas of high population density.

The original design has undergone considerable evolution over the years, equivalent almost to re-design and re-packaging. The system is now connectorized and does not necessarily require a forced air supply.

At the same time, a large PABX system was developed from the original E-10 central office. It has a lower traffic capacity than the central office version. Further, it is not yet connectorized (though it was explained that such a version will be available later), but it uses the same basic conponets (especially subscriber stages) as the central office.

Switching Network

The core of the switch is a nonblocking time-division network. In case of the central office version, a time-space-time configuration with a fully equipped capacity of 3,000 Erlangs is used. The PABX has a pure "time" network with a capacity of 1,500 Erlangs. In both cases, words are transmitted in parallel over the internal highways. No network parts are duplicated.

The time division matrix is built from TTL integrated circuits.

Subscriber Stages

While digital trunks interface directly with ports on the main matrix, subscriber lines use a special subscriber stage. Up to 512

subscribers may terminate on one such stage. At the analog side, a reed-relay concentrator is employed to connect any subscriber who goes "off-hook" to any of 60-line inputs. Two CODEC's, one for each group of 30 lines, convert between analog and digital signals. The digital signals are multiplexed into two bit streams, each of them of the European CEPT format.

Subscriber stages may be installed either locally, at the site of the switch, or at a remote location, in which case two 32-channel (CEPT) digitally multiplexed lines are used to connect this unit with the main switch.

Subscriber Line Circuits

The equipment manufactured by CIT-ALCATEL uses subscriber line circuits integrated with a reed-relay space-division concentrator of the kind just described. CNET (the research arm of the French PTT), however, has developed a different subscriber stage, named the EMA (improved version). Here, the analog voice signals are converted to PCM first, the concentration then takes place in a time-division switch. One CODEC is shared by 30 subscribers, while in the other approach, one CODEC is shared by up to 256 subscribers. CNET told us that all E-10 installations in France will be retro-fitted with this new design, while CIT-ALCATEL denies any intention to produce this EMA circuit. It should be noted, however, that CIT-ALCATEL is not the only manufacturer to supply the French PTT with E-10 equipment.

Common Control

The common control consists of the control unit itself which performs all call processing tasks and of a detached (remote) management center, which is responsible for all administrative and maintenance tasks.

The control unit uses the following components:

- Multiregisters - These are essentially specialized call processors performing most of the call processing tasks. There is a minimum of two multiregister units per system, larger systems use more, but one additional multiregister is

always provided for redundancy. The configuration is equivalent to a multiprocessor arrangement. Multiregisters contain memory which is accessible from the management center.

- <u>Markers</u> - They interface between the multiregisters and the switching network.
- <u>Translators</u> - Contains translation tables. Essentially consisting of semiconductor memory modules.
- Clock, peripheral units, etc.

All essential units, as multiregisters, markers and translators, are either duplicated or provided in a N+1 configuration to achieve sufficient redundancy.

The management center is a relatively powerful computer installation, provided on a regional basis in the case of a central office. It allows performance of all management tasks, including accounting and diagnostics, on all central offices of a geographic district. It is connected with the offices via 64 Kbps data links.

For application in the PABX, the management center has been scaled down. It serves one PABX only, but performs essentially the same functions as in the central office environment.

<u>Attendant Console</u>

Multiple consoles can be provided, the system can further be partitioned to serve multiple users.

<u>Features</u>

Most applicable features were checked as being available for the central office version, as well as for the PABX version.

<u>Features of Special Interest</u>

- 256 alternate routing options
- CIT-ALCATEL is developing interfaces to the North American T1 standard, as well as μ-law encoding. It is being under consideration to provide both standards on the same system if so desired.
- A militarized version has been developed for the French army, reportedly for application as a tandem switch. No information could be obtained as of yet.
- All of the military features in our questionnaire were checked to be either available, in service or easily included, with the exception of secure call mode/key conversion.

Circuit Switching of Data

An interface to connect a single line carrying 64 Kbps digital data to the switch has been designed for the purpose of connecting the remote management center. This interface could be provided for general purpose data transmission applications. Other speeds would need special provisions for bit-stuffing, etc.

System Advantages

- Many applicable features, including those in the quasi-military group.
- Data interface available.
- At a later time, both CEPT and T1 will be accepted, as well as both encoding laws.
- Allows completely remote operation.

System Disadvantages

- Reed relay subscriber stage not very attractive, has bad reputation as far as reliability is concerned.
- PABX not yet connectorized.

DANRAY

MANUFACTURER: DANRAY, INC., Dallas, Texas

TYPE: CBX/CTSS

APPLICATION: PABX, Tandem, Data Switch

TECHNOLOGY: PWM Space Division

SIZE RANGE: 500 to 8,000 Lines for the PABX
100 to 1,000 Trunks for the Tandem

DANRAY manufactures a range of products to cover the switching needs of a corporate telephone network. The CTSS tandem switch accommodates 100 to 1,000 trunks on a fully nonblocking matrix. It can perform network management functions and, in addition, control up to ten Remote Switching Subsystems, each with the capability to connect up to 244 trunks. These remote switches are intended for the intermediate switching level in a corporate network and perform the concentration of trunks, as well as through-switching between different remote units.

The CBX uses the same common control and the same matrix technology as the CTSS, but includes subscriber concentrator stages, as well as all subscriber related features. It is available in several configurations, with either 2,000, 4,000 or 8,000 lines as a maximum size.

The technology used internally to all these switches is pulse-width-modulation (PWM), but all lines or trunks carry normal voice signals, no PWM is used outside of any of the switches.

All of the DANRAY switches are designed to support the DANRAY Electronic Telset. This is a special electronic telephone instrument, which requires three wire-pairs to the exchange. Two pairs carry the voice (analog) signals in both directions, the third pair is used to supply power to this telephone. Normal two-wire telephones may be used as an option.

Both the CTSS and the CBX use the same common control. This common control can, in addition to the normal voice matrix, control the ADX data module, thus giving the system special data switching capabilities.

The remote switches use a rudimentary common control, which is normally under the command of the main tandem switch.

We learned that DANRAY has developed a fully digital PCM switch, using the same common control as in the present systems. No further information could be obtained except that the first switch will go into operation during 1978. (It is supposed to be a production unit, not a prototype or field test unit.)

Switching Network

PWM is used within the switching network. Each line or trunk interface has a PWM modulator and a PWM demodulator. Sample frequency is at 22 KHz. Although eight KHz would be sufficient, the higher frequency results in considerably lessened requirements for the filters on the analog transmit and receive side of the interface. Two-wire line and trunk interfaces further contain a hybrid circuit, which is of the active type, implemented with solid state components. All PWM modulators are free-running, not centrally synchronized.

The switching network is of modular design. Various types of modules allow the construction of a tandem matrix, a remote tandem matrix or a PABX matrix. Normal TTL-type logic gates are used as crosspoints.

The core of the matrix is a three-stage, nonblocking arrangement of these crosspoints. "First" and "fifth" matrix levels are available either as nonblocking trunk subsystems or as concentrating line subsystems. The line subsystems are available either for 0.095 Erlang per line or in the normal configuration of 0.21 Erlang per line. The remote switching units use only three matrix stages all together. NOTE: In all applications, both paths of a call are routed separately through the matrix.

A special duplicated control unit interfaces with the common control section of the switch. The matrix is not duplicated, but the space division principle has enough inherent redundancy to allow for occasional crosspoint failures. During the process of call setup, the path through the matrix is first tested automatically. If a matrix failure is detected, the call can be routed over a different path.

We understand that the fully nonblocking matrix (in case of the CTSS) uses a network with a reduced number of crosspoints, but which still allows connection of any given trunk with any other trunk at the same time. Since, with this design, established connections may block new calls, a special algorithm is used in the common control to re-route such calls without dropping them. This is possible without an audible "click" because of the speed of the crosspoints. It is still possible in this 1,000 port matrix, to connect 498 trunks with 498 other trunks in any possible combination and make the last through connection, we were assured. The result is quite remarkable: a fully equipped 1,000 trunk nonblocking matrix (without line circuits and without control unit) occupies about two-thirds of a frame.

The CTSS 1000 and CBX 1000 use one matrix module each as described above. Several matrix modules of the same size may be combined to arrive a higher traffic carrying capacity. The CBX 2000 uses two such modules, the CMX 4000 four to six.

Common Control

The common control uses a pair of GENERAL DATA "NOVA" minicomputers. Disk drives, as well as the interface between common control and matrix, are duplicated for redundancy. Teletypes, CRT terminals, line printers and magnetic tape units serve as system console and for other peripheral purposes.

A variety of signalling subsystems are available for these switches (see "features"). Further, various types of test equipment can be addressed under the diagnostic routines from the common control.

The system features, among other diagnostics, automatic line and trunk testing.

In addition to the general system features, DANRAY offers network management systems, which are implemented using the common control processing capabilities. Among those are, for example, a Universal Switched Network package, featuring uniform destination dialing, predictive routing (forward and alternate routing with

fallback, if all routes are busy), least-cost routing, off-line queuing with call back and call screening.

Features

Almost all of the general C.O. and PABX features in our questionaire were checked as either in service or availabe. All of the military system features were checked as in service or available, except for pre-programmed and broadcast conferencing, which were checked as easily included.

Features of Special Interest

- Allows local/tandem configurations.
- Allows tandem switching systems with remote nodes.
- Has seven levels of priority (override) service built-in.
- Offers network control software packages.
- Common control computer has excess processing capability which may be used to implement additional features.
- Trunks, as well as subscriber lines, are usually of four-wire configuration.
- Allows up to 250 independent user partitions with independent routing tables.
- Supports CCITT #4, CCITT #5, and CCITT #6, in addition to the usual signalling schemes.
- Up to 20 digits can be dialed.
- For data transmission capabilities see below.

Circuit Switching of Data

The switch can transmit up to 9600 bps analog modem data. Digital data may be switched directly through a special matrix module, the ADX. This is essentially a time multiplexed circuit switch, which currently supports asynchronous and synchronous data, including the bi-synch protocol, at up to 9600 bps. Line interfaces for higher speeds and other protocols, including SDLC, will be available later. Sixty-four Kbps will be possible later.

In systems with these data switching capabilities, DANRAY uses their special "electronic" telephone and transmits data up to 9600

bits per second in full duplex mode over the power supply wire pair (one of the three wire pairs which connect the telephone with the switch).

The digital space division matrix which is used to switch the PWM signals is transparent to any digital signal or bit stream, if a direct digital line interface where installed instead of the PWM modulator/demodulator interface. (Of course, the digital signals cannot be transmitted through a normal analog trunk. Here also, special interfaces and lines with the right properties would be required.) We were assured that such an interface, though not available, could easily be designed.

System Advantages

- If equipped with special interfaces on data lines and data trunks, any mixture of analog and digital signals, including CVSD could be switched in the same matrix.
- Very capable system, wide range of features available.
- Product line includes all elements for a complete network, including network contol software.
- Special data matrix can be used on same common control as voice matrix.

System Disadvantages

- Does not support PCM integrated transmission and switching concept.
- Only product of its kind.

GTE AUTOMATIC ELECTRIC

MANUFACTURER:	GTE AUTOMATIC ELECTRIC, Northlake, Illinois
TYPE:	GTD-120
APPLICATION:	PABX
TECHNOLOGY:	PCM Time Division
SIZE RANGE:	Up to 120 Lines

No technical or descriptive literature has been received from the manufacturer except for the questionnaire.

This is the smallest PCM switch in our survey. According to the questionnaire, it has a space-division concentrator and one CODEC for every 24/40 lines. It utilizes hard-wired logic common controls. It seems that only a very small PCM switching network is used, in addition to the concentrators.

Features

This system has fewer features than many other small PABX's in our survey. Particularly, no direct inward dialing, no emergency override, no abbreviated dialing, no change of features and no traffic analysis.

Features of Special Interest

- Accepts T1 (24 channel) trunks.

Circuit Switching of Data

No provisions.

System Advantages

- Small size
- In service experience
- May be used in integrated transmission and switching environments.

System Disadvantages

- No change of features, no traffic reporting, etc.
- Very little flexibility.

GTE SYLVANIA

MANUFACTURER: GTE SYLVANIA, Waltham, Massachusetts

TYPE: ETSS

APPLICATION: Transit

TECHNOLOGY: Solid State Space Division

SIZE RANGE: 96 to 1,536 Trunks

The first switch of this type was cutover in 1976, the second one in 1977. Twenty-two were on order earlier this year. Applications are either for transit or as international gateway exchanges. Thirty-four more switches, based on the same basic equipment, have been delivered to the Armed Forces. They use a militarized common control computer and are mounted in transportable shelters.

Switching Network

The matrix is built from modules of 96 trunk terminations. One fully equipped matrix system has 1,536 trunk terminations. Multiple matrix systems of this size may be used to build larger switches.

The switching matrix is built from SCR (silicon controlled rectifier) crosspoints. A four-by-four arrangement of crosspoints, including some of the control circuitry, comes in a standard I.C. package.

The matrix uses a four-stage arrangement. An interconnection pattern is used which assures a high availability. A 96 trunk configuration has a capacity of 0.95 Erlang per trunk, a 1,536 trunk matrix a capacity of 0.83 Erlang per trunk. Two-wire, as well as four-wire, service is available. A pair of crosspoints is used for each switched pair of wires. The actual trunk terminations are isolated from the crosspoints by transformers. The marker functions, as well as many routine functions, such as trunk supervision and maintenance tasks, are performed by the line group processor, a DEC PDP 11/04. This processor is equipped with 8K words of memory and a real-time clock. Each group of 96 trunks has one line group processor

Common Control

A pair of DEC PDP 11/34 minicomputers is used to serve up to one matrix unit of 1,536 trunk terminations. These perform the

functions of call processing, call accounting, traffic recording and others. Also, as part of the common control, there are two high-speed paper tape reader/punchers and up to six register/signalling shelves. A relatively wide variety of signalling concepts is supported by this system, among others CCITT #5, CCITT Rl, and CCITT R2.

Features

The manufacturer checked all features in the questionnaire which are applicable to a transit exchange, plus many PABX features, and indicated that all features listed under "military" are either in service or available. This obviously is a result of the mainly military range of applications of the system in the past.

Features of Special Interest

- o Range of available features is remarkable.
- o Data transmission capability--see below.
- o Interfaces with AUTOVAN, NATO, AN/TTC 38 and 39, as well as with the public networks in Germany, France, Belgium and Holland.

Circuit Switched Data

The technology employed allows data transmission at any speed. Manufacturer sets upper limit of analog bandwidth at 108 KHz. This would easily allow direct digital data transmission through the matrix of up to 64 Kbps. Since the switch is transparent to data, there are no restrictions on speed, format, etc. A special interface card is used for connection of four-wire data loops at these speeds.

System Advantages

- o Technology used allows almost unrestricted data transmission.
- o Since system has been in use for military applitions more than for commercial purposes, range of military features are available, as well as general operating experience.

System Disadvantages

- Does not support integrated transmission and switching.
- System likely to be expensive.
- Manufacturer gives reliability objectives which are not very impressive: ten hours of system downtime per 20 years, and a MTBF of 38 hours for the maximum configuration (1,536 trunks).

HITACHI

MANUFACTURER: HITACHI, LTD., Tokyo, Japan

TYPE: EX 10

APPLICATION: PABX

TECHNOLOGY: Solid State Space Division

SIZE RANGE: 100 to 1,024 Lines

This is a stored program controlled solid state analog switch for PABX applications in business, hotel/motel, CENTREX and others. It consists of one to four cabinets, each cabinet serving up to 256 lines.

Switching Network

The switching network is a solid state space division two-stage matrix. Since only two-wire subscriber lines and trunks are accommodated, it is assumed that the network structure is basically two-wire. The system may be expanded in eight-line increments. Traffic carrying capacity is from 39.4 Erlangs to 157.6 Erlangs. Normal telephone instruments are used in connection with this switch.

Common Control

A 16-bit common control processor is used, which was specially designed for this application. It has an instruction set of 40 instructions. Up to 112K words may be used in the memory. Programs are loaded automatically from a tape cartridge when power is switched on. The common control is not duplicated for redundancy.

Attendant Console

Station number, trunk number and class of service number are displayed. Status of all calls processed by attendant is displayed. Optional is the display of status of all lines.

Features

An overwhelming array of PABX features is available. All applicable features, including the military features (with the exception of secure call/key code conversion) has been checked on our questionnaire as being available, in service, or easily included.

Features of Special Interest

The processor is likely to have surplus processing capability, applicable for the implementation of other features.

Circuit Switched Data

No capabilities provided. Solid state space division technology generally allows the transmission of data of at least 64 Kbps over the matrix. However, special line interfaces (easily designed) would be required and operation would be restricted to two-wire service.

System Advantages

- o Many features for all kinds of applications available.
- o Technology used likely to be cost effective even in the future for this size range.

System Disadvantages

- o No four-wire operation.
- o Only loops of up to 1,000 Ohms allowed.
- o Common control not duplicated.

ITT

MANUFACTURER: ITT, Des Plaines, Illinois

TYPE: TCS 2/TCS 5

APPLICATION: PABX/Central Office

TECHNOLOGY: Solid State Space Division

SIZE RANGE: 600 to 12,000 Lines

The TCS-5 was developed by the ITT Telecommunications Group in Des Plaines, Illinois.

The TCS-5 is designed for use in the 600 to 12,000 line range, and can be applied as a PABX, CENTREX and as a local community dial office. The system supports a maximum of 12,000 lines and is engineered for approximately 1,400 Erlangs of total traffic. The system is tested in its entirety at the plant prior to shipment to the operational site. Installation time is typically three to six weeks.

The system employs a standard ITT 1652 minicomputer, and employs software line scanning. A combination of cross call status coordination, combined with load-sharing, is employed in the dual processors.

Switching Network

The system is a self-seeking, end-marked solid-state analog space-division switching system, utilizing a minicomputer common control. It employs the PNPN (four layer) diode for the analog crosspoint, with characteristics to ensure a unique path as established between two end-marked points, without the requirement for external path-selection equipment. These techniques have been successfully applied to the TE-400A PABX, a 50- to 800-line PABX system receiving wide acceptance in the United States. The system can handle 50,000 busy-hour calls, and 50,000 CCS of traffic.

The TCS matrix is a full availability four-stage matrix. The primary and secondary switches are grouped into line blocks having 20 inlets and 45 outlets. Line blocks are grouped into line sections such that one to eight line blocks may be connected at the secondary outlets to form a line section. Each additional line block changes the dimensions of the secondary stage by adding

inlets. The third and fourth switching stages are subdivided into trunk units, each containing nine third-stage switches, such that the 45 outlets from the second-stage switches are individually connected to the nine third-stage switches in the five trunk units. Each trunk block contains ten fourth-stage switches, each having three outlets for a total of 30 outlets per trunk block. Additional trunk blocks up to a maximum of eight is allowed, with the number of outlets in each fourth-stage switch at a maximum of 24.

The matrix is packaged on 8.7 by 10 inch printed circuit boards for mounting and standard ITT UNISWEP shelves. Line and trunk blocks require a single printed circuit board, while the third-stage switches are mounted three to a board. The total matrix volume is approximately 25 cubic feet, employing a maximum of four matrix units.

Because of the intrinsic difficulty of locating faulty crosspoints in an end-marked system, the TCS system utilizes fan-out control logic associated with the third-stage switches. This includes a simple buffer circuit which enables manipulation of the third-stage inlets under stored-program control. This program normally resides in a disk-storage device off-line, but is brought in during off-load traffic periods to perform fault analysis functions. It selects an inlet and outlet in the matrix, and proceeds to establish and release each of the nine paths between the end-to-end marked points by selectively busying the inlets to eight of the nine third-stage switches. Failures are noted and tested later to determine if the path is truly busy, or whether a fault exists. True faults are then printed out on the on-line teleprinter for maintenance attention at a later time. Importantly, in an end-marked system, faulty crosspoints reduce overall traffic handling capabilities only. Typically, a complete matrix test is run once a month.

Common Control

The TCS-5 system utilizes dual ITT 1652 processors, to perform totally centralized common control functions, including line scanning. This was done to reduce the economic lower-size limit. The

two processors are normally on-line and load-share originating traffic. Each processor, when recognizing an origination or change of call status, maintains control of that call for its duration. As each call progresses, relevant information is extended to the other processor to ensure that the status of all calls and equipment in this system is maintained within each processor. In the event a failure within one processor or its associated equipment occurs, that processor will be immediately taken off line. The remaining processor will take over control of all system functions without affecting their operation, with the exception of reducing further traffic handling capacity. Exclusion circuits are provided for each processor to eliminate the possibility of conflict.

The computers employed, the ITT 1652, operate in a load-sharing mode. Basic instruction time is 1.2 u seconds; semiconductor memory R/W cycle time of 600 nanoseconds. Word size is 16 bits plus 5 error-correction bits. 128K words is required for a small system, and 164K words for a large system. Off-line diagnostic programs are kept on a 150K word floppy disk.

Features

Most of the features listed in our questionnaire are available either for the PABX or the C.O. version or for both. This includes many of the administrative and traffic reporting features. Automatic line load control is available.

Features of Special Interest

As of this time, we have not been able to obtain information regarding the points in our questionnaire covering the semi-military specifications.

Circuit Switching of Data

Combined voice and data switching is being advertised for this system. The technology involved with the TCS network allows enough bandwidth to transmit at least up to 64 Kbps. It is not quite clear, however, whether the line circuit available for data lines will limit the actual bit frequency to a lower value. In any case, a slight modification of this circuit would allow transmission of up to 64 Kbps.

This switch is intended for Class 5 C.O. and PABX applications and, therefore, is basically of two-wire design. Unless it is possible to equip the whole section of the network which is to be used for data transmission with four-wire matrix modules, data transmission would be restricted to two-wire mode.

System Advantages

- Very compact system.
- Solid-state space-division allows unrestricted data transmission.
- Space-division network has a certain amount of built-in redundancy.

System Disadvantages

- This is a system designed about five years ago, exhibiting the state-of-the-art from that period.
- Obviously restricted to mainly two-wire circuits.
- Likely to be relatively expensive for a given size when compared with newly designed PCM systems.

NORTH ELECTRIC

MANUFACTURER: NORTH ELECTRIC CO., Galion, Ohio

TYPE: DSS-1

APPLICATION: C.O., Local and Transit Service

TECHNOLOGY: PCM Time Division

SIZE RANGE: 1,000 to 12,000 Lines

DSS-1 is the designation of NORTH's smaller PCM switch. The larger version, the DSS-2 covers the range of up to 64,000 lines.

NORTH ELECTRIC also developed a solid state space division (wideband) switch, based on the same common control as the DSS-1. This is the switch intended for the NATO Initial Voice Switched Network (IVSN), for which NORTH has won a contract. Further, NORTH plans to extend the capabilities of the IVSN switch by adding a digital matrix especially designed for CVSD. We were told that it will be possible to have both a solid state analog and a CVSD digital matrix section on the same switch, and that any or both of these technologies could be mixed with PCM digital matrix sections. This appears to be a very interesting concept for a number of military applications.

Switching Network

The basic configuration is of the time-space-time type. Subscriber loops interface with the DSS-1 line switches, which are self-contained frames. These contain the subscriber circuits for up to 320 lines each, plus the multiplexing equipment to switch the digital information associated with any of the lines into any of the 48 time slots of two outgoing T1 lines. Associated with each T1 line is a microprocessor with its own ROM and RAM memory which is responsible for the functions of the line switch, including multiplexing of the bit streams.

The DSS-1 switching group, a fully electronic time multiplexed switching matrix, interconnects the T1 lines from the various line switches. The switching group actually consists of two separate matrices in parallel, each with 50% of the total traffic-carrying capacity of the system. The two T1 lines from each line switch

always terminate on different matrices. Thus, in case either a matrix or one of the T1 connecting line becomes defective, calls can still be routed over the other T1 line and the remaining matrix. One frame contains up to five switch groups sufficient for a 5,000 line office.

Line switches may be remotely located, interfacing with the main switch through two T1 lines, requiring additional span terminating equipment. These remote line switches have an emergency local switching capability allowing calls between local subscribers (on the same remote line switch) to be dialed, even when both T1 lines into the central office are out-of-order. Remote line switches are also being advertised as temporary small central offices, since they have all the capabilities for providing basic telephone service.

Subscriber Line and Trunk Circuits

Subscriber line interface circuits use one CODEC per line. They are remarkable because they use an active hybrid, without any magnetic components. Further, the battery feed circuitry includes a feature to boost the supply voltage in order to accommodate loops of up to 3,000 Ohms without any external booster.

T1 multiplexed trunk lines can interface with the switch group through special terminating equipment. Interfaces for CEPT (32 channel) lines are not available, but are said to be planned for later introduction.

Analog trunks interface through standard channel banks.

Common Control

As mentioned earlier, each line switch has its own microprocessor which handles many basic real-time routines, as well as the interfacing of the line switch with the central control processor.

The central control processor, the OMNI V CPU, is an improved version of NORTH's line of specially designed OMNI processors. NORTH has maintained for quite some time that a special processor with an instruction set specially designed for telephony purposes is superior to the adaptation of a general purpose processor. We found it difficult to arrive at any kind of consensus about this topic among different experts in this field.

There are two processors of this type in the system, each with its own memory. They run asynchronously, with one always in "hot stand-by" mode. Larger systems (DSS-2) use more than two processors.

Teletypewriters, printers, and reel, as well as cassette tape drives, may be used as peripherals.

Features

A large number of C.O., as well as PABX type features, are either available now or are scheduled for introduction in a phased program over the next several years.

Features of Special Interest

The DSS-1, as well as the IVSN switch, use the same common control and may use the same hardware interfaces to various signalling systems. Therefore, any special features will be available in both switches. Specifically, the IVSN system will interface with the AUTOVON, the NATO, the German, French, Belgian and Dutch national network. The DSS-1 can be expected to have the same capabilities, except for interfacing with digital networks, because the CEPT digital interface is not yet available.

Circuit Switching of Data

No digital data interface is available for the DSS-1 as of yet. According to NORTH, such interface is easily designed.

The IVSN switch, however, which uses solid state space division network for up to 2,048 lines, can be combined with the network of the DSS-1 on the same common control. Thus, data up to more than 64 Kbps can be switched without any regard to internal bit rates of the matrix. Further, NORTH is developing a digital CVSD matrix which can be attached to the same common control.

System Advantages

- Allows flexible configurations with local and remote line switches.
- All interconnections between line switches and central switching groups are through T1 lines.

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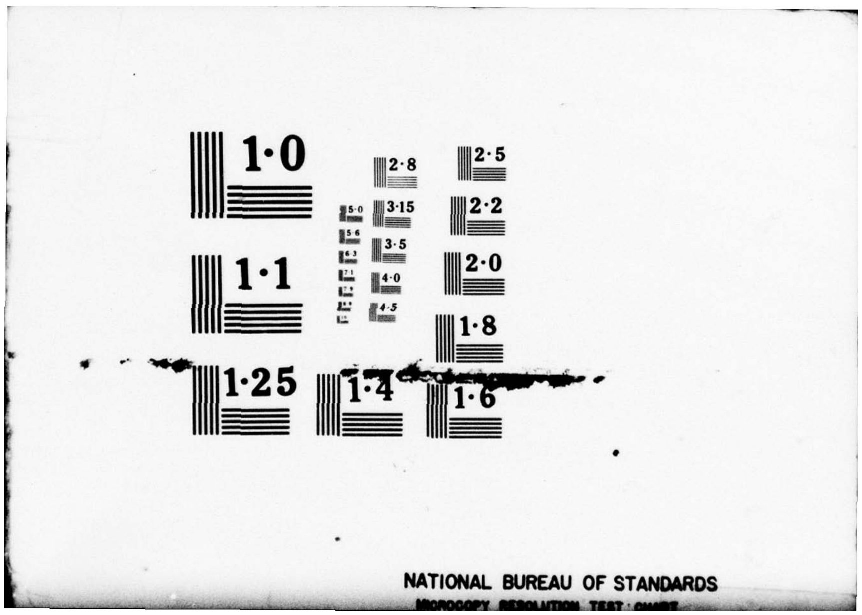
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NATIONAL BUREAU OF STANDARDS

- Allows mixing of two, and later of three matrix technologies (PCM, solid state space division, CVSD).
- Remote line switches can be used either as remote concentrators or as independent small PCM switches for up to 320 lines.
- Accepts loops of up to 3,000 Ohms without external booster.

<u>System Disadvantages</u>

- New system, no reliability information available.
- Many features not yet available.

NORTHERN TELECOM

MANUFACTURER: NORTHERN TELECOM, LTD., Montreal, Canada
TYPE: SL-1
APPLICATION: PABX
TECHNOLOGY: PCM Time Division
SIZE RANGE: 200 to 5,000 Lines

The SL-1 is NORTHERN TELECOM's first digital telephone switching system. The same basic hardware is used in the DMS-10, a central office developed out of the SL-1. There is currently an installed base of 350 SL-1 systems.

We asked the manufacturer to provide us with the same kind of information regarding the DMS-10, but received the answer that no effort is currently being undertaken to develop military features for the DMS-10, therefore, it would be unnecessary to fill in the questionnaire. Hence, only the SL-1 is reviewed here.

Switching Network

The switching network is of the time-space-time type. It consists of individual time switching modules of 17 Erlangs capacity each, which can be interconnected with a space switching arrangement. The "L" system, with 200 Erlangs total capacity, consists of 16 such modules, the "VL" system (maximum configuration) of 6 times 16 modules. System growth, however, is possible in smaller increments, which are given by the configuration of the line circuit cards. These contain either four line circuits or two trunk circuits each.

The switching network is not duplicated for redundancy but a hardware failure will not affect more than one module with 17 Erlangs capacity. Subscriber line concentration takes place on the digital side of the line circuits, using time-division switching techniques.

Subscriber Line and Trunk Circuits

One printed circuit card supports either four subscriber lines or two analog trunks. Each line or trunk is equipped with its own CODEC. Subscriber circuits use a CMOS/thick-film hybrid. Currently, only the North American μ-law is available. Although auto-

automatic loop and trunk tests are checked in the questionnaire to be available, we learned that these are only rudimentary, non-metallic tests. Subscriber loops up to 1,000 Ohms are supported. This is usually sufficient only for a PABX. We were not able to learn whether or not subscriber circuits supporting higher resistances are available. They are standard equipment in the DMS-10, however.

Interfaces for Tl multiplexed trunk lines are available. We learned that optional compatibility with European standards is currently being pursued and assume that this means availability of CEPT interfaces, as well as A-law encoding.

Remote Peripheral Equipment

This type of equipment supports line shelves for up to 200 or 300 lines in a remote location, connected with the main switch through two Tl lines. Switching is under control of the SL-1 common control, local calls between subscribers on the same remote unit are closed through local links, but are under control of the SL-1, thus freeing two channels on the Tl line.

Common Control

Two processors, one in "hot stand-by" mode, are used. They are specially designed for this application. Word length is 16 bits, minimum memory requirement is 56K words. Maximum memory capacity (for the VL system) is 256K words. Software is loaded from a magnetic tape cartridge unit.

A teletypewriter serves as system console.

A system with enhanced reliability for military applications is being developed. It will have duplicated memory, as well as duplicated busses.

Features

Practially all PABX and central office features in our questionnaire have been checked as available. Many of the diagnostic, administrative and traffic reporting features are available.

The SL-1 is originally intended to be used with the special SL-1 station set. This telephone utilizes two wires for voice and

two additional wires as a digital communications channel to the exchange, carrying all signalling, such as dialing, pushbutton actuation, ringing, etc. Normal two-wire telephones are supported as well.

Features of Special Interest

- o One alternative routing option is normally available; a special routing package allows two schedules (day and night) with eight alternate routes each.
- o AUTOVON precedence service (five level) will be available as a software update in 1978.
- o Interfaces are being developed to support NORTHERN TELECOM licensees in Sweden, Great Britain, France and Germany.
- o Enhanced reliability will be available in April, 1979 for military applications. This includes dual memory, a dual bus system, but no duplicated networks, lines or trunk interfaces.
- o At this time, the SL-1 is only available commercially packaged. A study is in progress to determine the requirements to package an SL-1 with Remote Peripheral Equipment (RPE, the remote concentrator) in an S-280 enclosure (hut).
- o MTBF (theoretical) for total system down is 15 years.
- o Target MTTR is 30 minutes. Current experience in Bell Canada is:
  - 80% of all troubles are handled on a remote basis, average time is 15 minutes.
  - 20% of all troubles require on-site maintenance and the average time to repair is 45 minutes.

Circuit Switching of Data

No provisions are currently made for direct transmission of digital data through the switching network. As with any other PCM switch, an interface for this purpose is technically feasible.

System Advantages

- o Very flexible PCM switch with an overwhelming list of features.
- o Installed base of over 200 systems guarantees a high level of operating experience and a high degree of freedom from remaining "bugs."

- NORTHERN TELECOM seems to be determined to have a militarized version of this system available within less than two years.

<u>System Disadvantages</u>

- Data switching in digital mode is not possible at this time.
- Supports up to 1,000 Ohms subscriber loops only.

ROLM

MANUFACTURER: ROLM, Santa Clara, California

TYPE: CBX

APPLICATION: PABX

TECHNOLOGY: PCM Time Division

SIZE RANGE: 100 Lines to 800 Lines

This is a PCM time-division system of the smaller size range. Roughly 300 such systems are installed as of today. Extension of the upper size limit of this equipment to 3,000 to 4,000 lines is planned.

Switching Network

Very little actual information about the internal system architecture was obtained from the manufacturer. There is, however, one important fact. The ROLM PABX, at least in its present form, uses a nonstandard 12-bit linear encoded type of PCM and a sampling rate of 12 KHz.

The PCM network obviously is a simple time switch with the 12 bits of each data word transmitted in parallel.

This type of PCM encoding, as well as the system structure, precludes direct compatibility with either the BELL T1 or the CEPT standard multiplexed PCM trunks. No special interface is offered as of yet; however, the manufacturer indicated that compatibility with both standards will be offered in 1980. An interface will be used which converts the 12 bit, 12 KHz sampling rate of the internal PCM into either the T1 or the CEPT PCM standard, resulting in the appropriate encoding law in each case. The interface will use a digital algorithm.

The entire switching network is duplicated for enhanced reliability.

Subscriber Line and Trunk Circuits

Only analog trunks and analog subscribers can interface with the switch. One CODEC is shared by 16 lines. Encoding is in linear PCM, 12 bits per word and at a sampling rate of 12 KHz. The high sampling rate results in significantly reduced specifications and cost for the transmit and receive filters.

Although two- and four-wire trunks are available, only two-wire subscribers can be connected as indicated in the questionnaire. We were told, however, that four-wire subscriber circuits could be provided as an option. The line gain is adjustable under common control

Interfaces to both BELL T1, as well as to CEPT PCM trunks, are planned to become available in 1980. They will use a digital algorithm to convert between the internal and the external PCM standards.

Common Control

A modified version of the ROLM 1603 minicomputer is used in the common control section. The ROLM 1603 is a "ruggedized" version of the DATA GENERAL "NOVA" computer. In this case, the "ruggedization" has been lost to a certain degree by substituting less expensive commercial components for the normally used high quality types. It appears to be entirely feasible to substitute the regular ROLM 1603 for this modified version if so desired.

Two processors are provided per system for purposes of redundancy. Software is read into memory from magnetic tape cassettes. No overlays are used, all programs are always in memory.

A service teleprinter serves as the system console. It may be located on-site or remotely.

Features

All of the PABX features in our questionnaire were checked as either in service or available. Many traffic reporting, as well as diagnostic capabilities, are available. Remote reporting is accomplished over voice lines with modems. Dial-up reporting is available.

Features of Special Interest

From our list of military features, only progressive conferencing, direct access service, zone restrictions and unrestricted numbering are checked as being in service. All others are difficult to include.

For data, see the next heading.

Sixteen alternate routing options are available.

Circuit Switching of Data

Modem signals of up to 9600 bits/second may be transmitted over the switch. The manufacturer indicated that an interface for digital data, to be used instead of a subscriber line circuit, may be easily designed.

With an internal rate of 144,000 bits/second for each voice channel, more than 64 kilobits/second could easily be accommodated. However, the planned interface to digital trunks, which will include a PCM standard conversion, precludes transparent operation within an integrated switching and transmission network.

System Advantages

- o Very compact PCM system, specifically designed for the size range below 1,000 lines.
- o Many features available.
- o High degree of redundancy.
- o System may be expected to have excessive processing power, useful if additional features have to be implemented.
- o 300 systems installed, with considerable operational experience.

System Disadvantage

- o Uses nonstandard PCM.
- o Even with proposed PCM trunk interfaces, no data integrity possible when transmitting over digital trunks.

SIEMENS

MANUFACTURER: SIEMENS Corporation, Iselin, New Jersey

TYPE: SD-192

APPLICATION: PABX

TECHNOLOGY: Solid State Space Division

SIZE RANGE: 48 to 192 Lines

This system has been developed and is being built especially for the U.S. market by the SIEMENS Corporation, Iselin, New Jersey. It is intended for general business applications. A hotel-motel PABX based on the same hardware is expected to be announced in the first half of 1978. It will allow a maximum configuration at least twice the size of the SD-192.

Switching Network

In the minimum configuration, this solid state space division network is fully nonblocking. The maximum configuration of 192 lines and 48 trunks has a capacity of about 36 Erlangs, allowing 0.22 Erlang per line under the assumption of 30% intraoffice traffic.

No redundancy increasing design measures are incorporated into this small switching network.

Common Control

This system is stored program controlled using an INTEL 8080 microprocessor. CPU's are not duplicated for redundancy. The SD-192 uses a tape cassette drive for loading of software.

Peripherals include a local or remote printer and a detachable small terminal, which serves as an operator's console and may be used locally or remotely. It is the size of a small desk-top calculator and has a numeric keyboard plus special funtion keys, as well as an online alphanumeric LED display. All data and feature changes, as well as report requests are initiated from this terminal in a very simple code. Output is either to the printer and/or to the LED display.

Attendant Console

Compact and easy to understand. Calls are displayed giving trunk group and number, as well as station number and class of service. Status of all trunks and the time of day is always displayed. An optional, separate display unit indicates the status of all stations.

Features

Those listed in summary tables and some more.

Features of Special Interest

System runs on 115 V A.C. and allows for an exceptionally wide range of supply voltage: 85V to 130V (57 Hz to 63 Hz). Optional 48 V D.C. supply module available.

Memory has special protection circuitry, preserving content of the (semiconductor) memory through short power interruptions. Only power interruptions of longer duration require reloading of software, which takes place automatically and requires 90 seconds after power is restored.

Circuit Switching of Data

Technology of switching network may be expected to allow transmission of data of any speed up to at least 64 Kbps, but no line or trunk interfaces for such mode of operation are available. This would require special design effort.

System Advantages

- Offers all the essential PABX subscriber and system features listed in our questionnaire, except two party hold on console, line and trunk testing capability, and some of the more sophisticated reporting functions.
- Change of data and administration of system from special terminal made so easy as to require little training of operator responsible for this task.
- The range of sizes are well within what we consider the domain of solid state space division switching for quite a number of years to come.
- Solid state space division matrix has the general capability to transmit circuit switched data.

System Disadvantages

- Relatively new, no actual reliability information available as yet.
- Neither common control nor matrix duplicated for redundancy.
- No interface for digital data offered, though technically feasible.

MANUFACTURER: STROMBERG-CARLSON, Rochester, New York

TYPE: Century DCO

APPLICATION: C.O., Class 5 and Class 4/5

TECHNOLOGY: PCM Time Division

SIZE RANGE: 200 to 20,000 Lines

The CENTURY DCO series covers a wide range of system sizes. This has become possible through modular design, as well as through an arrangement of functionally distributed processing. (STROMBERG-CARLSON does not use the term "multiprocessor system," but, in our opinion, it might as well be used.) Further, the call processing computer uses two members of a family of upward compatible computers, depending on system size.

Switching Network

The switching network is of the time-space-time type. Appearances on the network are organized into port groups of 30 individual ports, the digital information from these ports is multiplexed into one port group highway. Eight port groups are connected with one time-slot interchange (TSI). Thus, up to 8 times 30, or 240 ports (each equivalent to one line or trunk) are connected with one TSI, which may pick up to 128 of them and insert their bits into one of the 128 time slots of the associated cross office highway. Up to 32 TSI's may be used in one network, resulting in 7,680 ports and a total traffic capacity of 2,816 Erlangs. NOTE: An optional 8,000 Erlang matrix will be available soon.

Each port group has its own port group control, each TSI its control store and each group of eight TSI's has its own telephony preprocessor and associated circuitry.

The whole switching network, including port group control, TSI's with control and telephony preprocessors, is duplicated for redundancy. One system is normally operative, while the other is in a "hot stand-by" mode. Both are being monitored for proper function through diagnostic software from the maintenance processor and, whenever the operating unit shows a malfunction, the other unit is put on-line.

Subscriber and Trunk Circuits

Subscriber line, as well as analog trunk circuits, use one CODEC per line. Both two- and four-wire subscriber lines, as well as two-and four-wire analog trunks, are supported u law or A-law is available. Analog trunks are accommodated with specially designed interface cards (not standard channel banks), allowing quite a number of signaling systems.

Two-wire interface circuits use an active hybrid circuit, subscriber loops may have up to 1900 Ohms. Also, T1/D2, as well as 32 channel CEPT, interfaces to digital trunks are available.

Common Control

Three levels of processing are used: Call processing takes place in the call processing system, using a DEC LSI 11 for switches of up to about 5,000 lines (exact limit depending on number of features). Above this size, a DEC PDP 11/35 is used. Both processors are upward compatible. The call processing system is duplicated for redundancy, each one is equipped with its own memory. One is normally operating, the other one in "hot stand-by" mode STROMBERG-CARLSON has designed special interfaces to the basic DEC processors to allow an extended addressing range, as well as the use of error correcting code.

The call processing system communicates with the telephony processors, which are dedicated microprocessors. They take care of most real-time tasks: line supervision, certain signaling-related functions and certain network control functions. There is one telephony preprocessor for each group of eight TSI's, duplicated for redundancy.

A maintenance processor (not duplicated) runs all administrative and diagnostic programs, including the generation of test calls. It uses floppy disk drives for off-line software storage and also initializes the system and loads the programs from the floppy disk into the call processor.

The usual range of peripherals may be used on the common control, either locally or remote.

Automatic line and trunk tests, as well as a large variety of diagnostics, are executed under control of the maintenance processor.

Features

Those available are listed in the summary table. Most of the C.O. features from our questionnaire are available. Many PABX features are included in a CENTREX package.

Features of Special Interest

- o System has a high degree of built-in redundancy all of the switching network and common control has been fully duplicated.
- o System can control remote concentrators and satellite offices.
- o High degree of modularity, covers a large range of office sizes.
- o An optional 8,000 Erlang matrix will be available soon, allowing either larger configurations or higher traffic per line.
- o Accepts both T1/D2 and CEPT digital trunks, as well as both u-law and A-law encoding options.

Circuit Switching of Data

The manufacturer checked this item on the questionnaire. We subsequently learned that a digital data interface is under consideration, but has not been designed. We were told that such an interface would be particularly simple, because of the design of the switch, which handles PCM signals by the bit instead of by the word, as most other switches do. However, we cannot really see that this will be of much significance as far as cost of this interface is concerned.

System Advantages

- o High degree of redundancy.
- o High degree of modularity. (There is even a PABX, based supposedly on the same type of hardware. We have not been able to get sufficient information about this PABX.)
- o Large number of features available, including PABX features in the C.O. CENTREX packages.

System Disadvantages

- o This is a new system,little actual operating experience available as of yet.

TRW VIDAR

MANUFACTURER: TRW VIDAR, Mountain View, California

TYPE: ITS 4, ITS 5, ITS 4/5

APPLICATION: Class 4, Class 5, Class 4/5 Operation

TECHNOLOGY: PCM Time Division

SIZE RANGE: 3,072 Trunks or 12,768 Lines plus 1,104 Trunks

VIDAR has developed the ITS Integrated Transmission and Switching System around the ITS 4 Base Switch. This unit evolved from the design of the former IMA 2 tandem system. It has an essentially digital, nonblocking network with either 64 (before third quarter 1979) terminations for 24 channel T1 multiplexed trunks, or 128 such terminations (after third quarter 1979). This switch, equipped with a common control section, may be used in tandem or toll-tandem applications either for digital trunks or, with additional channel banks with analog trunks. It may further be equipped with Local Subscriber Switches (LSS) or Remote Subscriber Switches (RSS). Each of those units supports up to 336 subscriber lines, and has 33 Erlangs traffic carrying capacity. The former connects to the Base Switch via two DS-1 network ports, allowing reduced traffic carrying capability even with one T1 line down.

In Class 4 operation, the ITS Base Switch, in its planned larger configuration, has a capacity of 3,072 trunk terminations. In Class 5 operation, the capacity is 12,768 subscriber lines (38 subscriber switch units) and 1,104 trunks. It is possible to trade 48 trunks for 336 lines.

Switching Network

The switching network of the Base Switch (ITS 4) is of the folded, nonblocking type. It interfaces with T1-type multiplexed 24 channel lines; 16 such lines terminate in one line group. The system can have up to eight line groups, equivalent to 128 T1 (DS-1) ports or 3,072 individual terminations. The line groups store all incoming PCM information temporarily in memory, using a re-derived

clock (from incoming lines). Information is read out of these memories with the internal "master clock." The "A" and "B" signalling bits are split off and sent to the signal processor at this point. The PCM voice information from 16 T1 lines is multiplexed into a 3.088 megabits/second parallel stream. There is, of course, one such stream in each direction. These bit streams finally interface the line group with the time-slot interchange (TSI). The TSI allows the interchange of information contained in individual time-slots of the multiplexed bit streams in such a way as to connect each channel from each of the port groups with each other channel in the same or in any other port group, while preserving full availability at all traffic conditions. This interchange of information is controlled by the content of a "call store," which is part of the TSI. This call store consists of a semiconductor memory. The system controller may establish or drop calls by writing into or deleting information in this memory. The TSI can transmit a memory map to the system controller on command.

All parts of the network, in which a single failure can cause system failure, are duplicated for increased reliability.

Common Control

The system controller uses two pairs of synchronously redundant INTEL 8080 microprocessors. In normal operation, one pair is used for call processing, the other for diagnostic and administrative tasks. If a failure is detected in the call processing pair (if there is a discrepancy between the outputs of the two), then the other pair is substituted and continues with call processing.

A separate signal processor receives the "A" and "B" signalling bits from the incoming PCM words and inserts the appropriate bits into the outgoing PCM words. The signal processor also receives framing error and parity error alarms and initiates path continuity tests. It communicates with the system controller.

A service generator switches digitally generated signals to the proper time-slots on command from the system controller. It allows the generation of dial tones, ringback tone, reorder tone, etc. The MF sender/receiver group occupies one T1 interface slot on the line group. It is also under control of the system controller.

Trunk Interfaces

The Base Switch connects with T1 lines directly. Analog trunks are interfaced to channel bank equipment.

Subscriber Switches

Adding either Local Subscriber Switches (LSS) or Remote Subscriber Switches (RSS) to the ITS 4 Base Switch allows the connection of subscriber lines and results in a Class 5 or a Class 4/5 configuration. The remote switches make possible the concept of distributed switching.

Further, a Subscriber Carrier Terminal (SCT) can serve up to 24 subscribers, and may be connected with either a LSS or a RSS via a T1 line.

The LSS (subscriber line concentrator) consists of up to 336 subscriber circuits, which serve one subscriber each and convert between analog and PCM signals. The PCM signals may be multiplexed into any one of 48 channels (equivalent to two T1 lines) which interface with two DS-1 ports on the Base Switch. This way, access to one of the 48 channels means full availability.

The RSS has the same configuration, but is equipped for remote operation. It is connected with the Base Switch via two T1 lines. The RSS has additional local switching capabilities, provided on a stand-by basis, in the event of a breakdown of both T1 lines to the Base Switch. This gives a stand-alone POTS capability. In any event, outage of only one of the T1 lines reduces traffic carrying capability, but does not bar access to the Base Switch for any of the local subscribers.

Connection of the SCT, which may be located remote from either a LSS or a RSS carries the distributed concept even further. Specifically, it brings the CODEC closer to a group of subscribers, substituting a length of two twisted pairs (of the T1 line) for up to 24 pairs (analog subscriber loops).

Subscriber Circuits

Subscriber circuits use one CODEC for 24 lines. Only μ-law encoding is available. The hybrid is manually adjustable. Two-wire, as well as four-wire circuits, are available. There is a

large variety of special subscriber circuits, covering most any application in the central office environment.

Features

All applicable features in our questionnaire were checked as either available now or in 1978-1979. This includes line and trunk testing, as well as most traffic monitoring and administrative features.

Features of Special Interest

The items on our list of military features were checked to be either available, in service or easily included, except for secure call mode/key conversion.

According to VIDAR, five level military call precedence would be easy to implement, given a CCIS type signalling plan to provide travelling class marks. VIDAR will provide CCIS when required.

Circuit Switching of Data

VIDAR indicated, that data of up to 64 Kbps could be easily transmitted through the switch (in the case of 64 Kbps, CCIS is required in order to save the D2 signalling bits for use in the data word. CCIS can be provided, according to VIDAR. We have not been able to learn whether an interface already exists, or if the VIDAR T1 data terminal may be used for this purpose. We assume that this data terminal, if not suitable, could relatively easily be modified.

System Advantages

- The ITS is a product line which allows the implementation of integrated transmission and switching concepts, as well as concepts of distributed switching, with a flexibility which is relatively unique.
- Six ITS 4 systems are in service, one over 18 months. New systems are being installed in a fast sequence. Therefore, it can be expected that within a year or two extensive operating experience (and a certain degree of freedom from "bugs") will be available.

System Disadvantages

- Does not support the European PCM standard.
- According to VIDAR, not easy to "ruggedize." Shock and vibration tolerances are low, due to large PC board size.

TELEFONBAU UND NORMALZEIT

MANUFACTURER:	TELEFONBAU UND NORMALZEIT, Frankfurt, Germany
TYPE:	III W 6030 Z and III W 6030 E
APPLICATION:	PABX
TECHNOLOGY:	PAM Time Division
SIZE RANGE:	1,000 to 3,000 Lines for III W 6030 Z 100 to 800 Lines for III W 6030 E

This PABX has been sold in Germany and other countries. The first installation was cutover beginning of 1975. This system and the WESTERN ELECTRIC "DIMENSION" are the only PAM switches in our survey.

Switching Network

For a general description of PAM switching technology see section "A" of this chapter.

The III W 6030 E, the smaller of the two configurations, uses a one-stage PAM matrix and accommodates 100 to 800 lines and 10 to 80 trunks. The III W 6030 Z has a two-stage PAM matrix and accommodates between 1,000 and (normally) 3,000 lines and 100 to 500 trunks. Larger configurations are possible.

The internal sample transmission rate is eight KHz.

In the larger switch (Z), the matrix is completely duplicated for redundancy, but not in the smaller configuration (E).

Subscriber Line and Trunk Circuits

Two- and four-wire trunks as well as two- and four-wire subscribers can be accommodated. All two-wire circuits use a three-inductor hybrid circuit.

A PCM multiplex interface for the European standard is available for the larger switch. Here, PAM signals are switched into a common bus and assembled in the desired sequence. The PAM multiplex is then applied to a CODEC.

Common Control

Hardwired logic performs many of the basic routines required in the system. A pair of TEXAS INSTRUMENTS 960 minicomputers (a single one in case of the smaller III W 6030 E) is used in the common control.

The common control computer also performs the diagnostic and administrative routines.

System console consists of keyboard, printer and tape unit.

Attendant Console

More than one attendant console may be attached, depending on the call handling requirements and size of the switch. All calls are individually displayed at the console, as is the status of lines and trunks.

Features

The larger switch has all the PABX features listed in our questionnaire; the smaller one most of them. A reasonable variety of diagnostic and traffic reporting features are available. An automatic call distributor configuration is available.

Features of Special Interest

- PCM CEPT (32 channel) interface available for III W 6030 Z
- See next section for data features.

Circuit Switched Data

The 6030 system is used in special configurations for business data acquisition purposes. A variety of data terminal instruments are available which are either mechanically combined with the telephone instrument or used separately. Data of up to 9600 bits/second may be circuit switched through the telephone switch, while higher data rates use separate lines. These lines connect directly with a data assembling separate minicomputer, while the data which travels through the telephone switch are connected with this computer through special ports.

The manufacturer has successfully transmitted data of 64 Kbps through the telephone switching network in an experimental installation. No such provision is offered for sale as yet.

System Advantages

- System in use since beginning of 1975. Can be expected to have "matured" to quite some degree of reliability and freedom from software "bugs."

- No quantizing noise as in PCM systems.
- System common control has excessive processing power, may be used for additional software tasks or features.
- May interface with PCM CEPT multiplexed trunks.
- Data switching available to a certain degree.

<u>System Disadvantages</u>

- PCM compatible to a small degree only.
- Data transmission through switch for over 9600 bits/second not possible.

MANUFACTURER: WESCOM, Downers Grove, Illinois

TYPE: 580 DSS

TECHNOLOGY: PCM Time Division

APPLICATION: PABX

SIZE RANGE: 80 to 2,400 Lines

This is a PCM time division PABX, featuring a fully nonblocking switching network. It is implemented with a unique multiprocessor architecture, using a concept of "democratic" functionally distributed processing. All processors are INTEL type 8080 microprocessors.

Switching Network

Subscriber circuits and trunk circuits convert voice signals to PAM, one CODEC converts 24 multiplexed PAM channels into PCM. Inputs and outputs from four CODEC's, corresponding to 96 channels, are multiplexed together in a first-order multiplexer. Subsequently, eight such 96 channel multiplexers are multiplexed into a bus with 772 time-slots (768 active plus four). There is an incoming bus and an outgoing bus. The eight-bit PCM words from the incoming bus are written into a semiconductor memory as they come in. Then they are read out in a different sequence, according to the desired call connections and placed into the time slots on the outgoing bus.

Up to four such switching modules as described, each serving 768 lines may be combined to form a matrix of about 3,000 ports (2,400 lines plus 600 trunks). Nonblocking interconnections between the modules are provided by the following technique: Each module has enough memory to allow writing of all samples from all four busses. Thus, samples for the outgoing bus in each module may be selected from those on all incoming buses.

In any matrix configuration, one spare module is provided. The fully equipped matrix thus consists of five modules. The spare module is switchable to replace any of the normally operating modules in case of failure, or during maintenance.

As can be seen from this description, no concentration is used. This matrix is completely nonblocking.

Subscriber Line Circuits and Trunk Circuits

Both types of circuits use one CODEC for every 24 lines. While the trunk circuits are of conventional design, the line circuits are remarkable because they use a fully solid state circuit which performs the functions of the hybrid, of battery feed, line supervision and line balancing as well as, to a certain degree, protection against overvoltages. Filters are of the usual active type, using thick film technology and Laser trimmed resistors.

Line gain is adjustable under common control. This is achieved in a unique manner. Switchable digital attenuators are inserted into the multiplexed bit stream behind the digital multiplexer stage. They adjust the gain (or loss) of each individual channel according to a look-up table. The look-up tables may be changed from the common control.

Common Control

The common control complex consists of a series of INTEL 8080 microprocessors arranged to provide distributed processing. Six different processors are used, each one assigned to a different task. Each one is also duplicated for redundancy. The processors are:

- A line processor
- A trunk processor
- A state processor
- A register processor
- A data base processor
- A console processor

This scheme is contrary to that of many other switches, where load sharing processors are used. Further, the processors in this system are not interrupt driven, but continuously "scan" for events. Interprocessor links and buffers allow the processors to communicate with each other.

A floppy disk unit stores the software package. It is only accessed to reload after the system is shutdown.

Various software packages are available, each one contains all the features offered for that particular application.

Maintenance features equivalent to those required for a central office are provided, with the exception of automatic line and trunk testing. Remote access for diagnostics, administrative procedures and traffic supervision are provided.

Features

Most of the central office, as well as of the PABX features, were checked in our questionnaire.

Feature packages for many specific applications are available. Also, CENTREX, as well as multicustomer operation, is supported.

Features of Special Interest

All of the military features in our questionnaire, with the exception of secure call mode/key conversion and data switching, were checked to be either in service or easily included.

Others include:

- o Gain adjustable under common control software.
- o High traffic rating on all lines (matrix non-blocking).
- o Interfaces directly with T1 trunks.
- o Accepts two- and four-wire lines and trunks.

Circuit Switching of Data

No data interface is provided. Although data may be transmitted directly through any PCM switch, the WESCOM 580 DSS seems to be the least suitable, because of its adjustable digital attenuators. It should be checked, however, if it would not be sufficient to set the gain in each line or trunk used for data transmission to 0.0 db gain in order to maintain data integrity.

System Advantages

- o High traffic capacity, 1 Erlang on all lines and trunks.

- Four-wire lines and trunks accepted.
- Lightweight, because no transformers used in line circuits.
- According to the manufacturer, this particular multiprocessor approach makes it easy to include additional software generated features.

System Disadvantages

- At present, allows subscriber loops up to 1,000 Ohms only (extension to 1,600 expected).

WESTERN ELECTRIC, Winston Salem, N.C.

MANUFACTURER:	WESTERN ELECTRIC, Winston Salem, N.C.
TYPE:	DIMENSION 400 and DIMENSION 2000
APPLICATION:	PABX
TECHNOLOGY:	PAM Time Division
SIZE RANGE:	DIMENSION 400: 400 Lines DIMENSION 2000: 2,000 Lines

As of this writing, the manufacturer still declines to provide more information than that contained in the incomplete questionnaires and in the feature oriented sales brochures. Specifically, technically-oriented system specifications could not be obtained, particularly data on busy-hour call attempts, busy hour calls, etc.

The Switch

The 400-line version, as well as the 2,000-line version, of the DIMENSION PABX is included in our survey. A DIMENSION "CUSTOM" is available, which accepts up to 5,000 lines, but is otherwise similar to the 2000 model.

The switch uses PAM internally in combination with time division switching. No other details could be obtained.

Features

A very comprehensive list of PABX features is available, including many administrative and traffic reporting features. The features checked in our questionnaire for the three different size ranges (Models 400, 2000, Custom) are nearly identical.

Features of Special Interest

Interfaces with AUTOVON, NATO, AN/TTC 38 and 39, as well as with the national networks in Germany, France, Belgium, and Holland, are available.

Circuit Switching of Data

No provisions made; difficult to include.

System Advantages

- Impressive list of features.
- The DIMENSION switches are expected to be the PABX's in this size range which the Bell System

will install in the years to come. Therefore, enough operating experience will be available, at least in the near future. Also, software and hardware bugs may be expected to disappear more quickly because of the volume of switches involved.

System Disadvantages

- No military features available yet.
- Data, as well as CVSD transmission capabilities, likely to be difficult to include.

III

OBSERVATIONS AND CONCLUSIONS ON MEETING QUASI-MILITARY SPECIFICATIONS

The purpose here is to make observations and to draw conclusions on the ability of the manufacturers currently offering advanced commercial electronic telephone switching equipments to meet a minimum set of military environmental requirements.

A. ENVIRONMENTAL STANDARDS

It is our conclusion that the broad range of commercial equipment surveyed could easily meet a requirement for operation within 0° C to 60° C ambient temperature in the operating area. They should also be able to withstand short-term periods of temperature substantially in excess of this. Above 60° C, the systems should operate but an increased failure rate for components may be expected.

From a humidity viewpoint, current commercial systems could provide 20% to 80% without any change, and could likely be extended from 10% to 90% through the use of ceramic integrated circuit devices, possible change of some resistors, and capacitors to higher ratings. Further, fungus coating may be necessary for portions of the system. These are considered to be relatively modest cost modifications to such existing commercial systems. However, because the relative small size of anticipated military procurements for small switching systems, we doubt if commercial suppliers wouild be willing to undertake such modifications without contractual sponsorship of these modifications.

The shock and vibration standards for use in a van-mounted environment, assuming that the system is not operational during the time when the van is moving, appears not to be a significant problem for the manufacturers of modern commercial electronic switching systems. Most of these utilize some form of van transportation for delivery to their customers, and little difficulties have been found in such shipments. It is not unlikely that the shock encountered in such shipment may be at least equal to that to which the equipment would be subjected in a military environment.

With regards to operation in a heavy electromagnetic radiation field, it is assumed that this equipment would be mounted in a van which incorporated Faraday cage-type protection for this system. Hence, we assume that these commercial systems would be fully capable of operating within this environment.

For fungus protection, particularly for long-term storage in high humidity conditions, it appears that commercial manufacturers could utilize a number of measures which would not be excessively costly to reduce the vulnerability of their systems to such attack from fungus. Coating of the printed circuit boards with anti-fungus material, the use of paint which is not easily attacked by fungus, and utilizing connector blocks which are fungus resistant would be the major measures. We assume that under these conditions, ceramic-type encapsulation for the integrated circuit devices would be employed, rather than plastic encapsulation. The standard coating would probably be applied not only to the PC board, but to the components as well to provide fungus resistance.

We were not able to obtain information on the effect of electromagnetic radiation, of the type accompanying a nuclear event, on this class of equipment. Therefore, our conclusions are based upon usage in a benign military environment.

B. SUBSCRIBER AND SYSTEM FEATURES

1. Military System Features

We will make observations below as to the ability of commercial switching system manufacturers to meet military subscriber and system feature needs, and to comment upon the reasons for the difficulty or ease which these may be achieved.

Five Levels of Precedence Service

Eight systems have this feature currently in service, according to the results of this survey. We are certain that at least Collins has this feature fully operational on their system. Seven additional systems are described as being able to be easily incorporate this feature into their software.

We should like to point out that five level military precedence is subject to a wide range of interpretations. Typically, those familiar with military systems include the ability to interrupt, not only calls in progress for a higher priority call, but also to interrupt the call set-up or call knock-down procedures, in order to immediately process a high precedence call. We believe only a few systems incorporate this latter more sophisticated form of precedence assignment. However, we seriously doubt if the more sophisticated version of precedence assignment is required, since the typical processor time required for the set-up or knock-down of a call is in the range of 20 to 30 milliseconds. This delay would not even be noticeable to the high precedence caller.

We seriously doubt if any of the PABX suppliers of commercial equipment have really looked seriously at the problems of passing along, in the signalling sequence to other offices, the precedence indicators, or of decoding the incoming signalling to also receive precedence indications. Hence, those who have answered affirmatively to the provision of five level precedence are speaking primarily of providing outgoing access to the trunk line, and its use internal to the local switching system.

NORTHERN TELECOM will have a partially militarized version of their SL-1. It is rather a version with enhanced reliability. It will have duplicated busses and memory as well as certain military software features. This will be available in 1979. In 1978, an AUTOVON type of five-level precedence feature will be available.

Additional ruggedization, as well as mounting in a S 280 enclosure is being studied at present.

Fixed Directory Translation Table

Only NORTH ELECTRIC, COLLINS, CIT-ALCATEL, DANRAY and GTE indicate that this feature is currently in service. Six additional systems are indicated to permit easy implementation of this feature.

In general, in a stored program system, the assignment of any line termination with a specific identifying called number can easily and rapidly be made at the maintenance console.

Conferencing

We should first like to point out that, in all of the current commercial switching systems, conferencing can only be accomplished with subscribers utilizing the same form of transmission. The greatest difficulty would arise in attempting to conference a CVSD subscriber with another CVSD subscriber, or with a PCM subscriber or an analog subscriber. A special conferencing bridge would be required to permit this. We understand from our discussions with the Rome Air Development Center that such conference bridges do not exist in the United States for CVSD to any other subscribers, regardless of transmission technlogy.

For progressive conferencing, nine systems are indicated to have this feature available or in service. This feature may be easily included in an additional five systems.

Preprogram conferencing can be provided as a standard feature available or in service with six systems. An additional ten systems are indicated to have this feature easily incorporated.

One-way broadcast conferencing is indicated to be available or in service in three systems, but is indicated to be easily incorporated in an additional thirteen systems.

Secure Call/Key Conversion

Firstly, key conversion is significant only if digital signals can be transmitted at an appropriate speed. We interpret this feature to provide a means by which two subscribers with different encrypting schemes can be permitted to hold a conversation, or an encrypted subscriber with an unencrypted subscriber (digital), or an encrypted with an analog subscriber. Only one of the manufacturers indicated that a feature of this nature is either in service or available. Only three manufacturers indicated that this feature might be easiliy included. All other suppliers indicated that it would be difficult to include.

Direct-Access Service

This feature is interpreted to be essentially a nondial "hot-line" service for specific subscribers. Twelve systems are indicated to have this feature available or in service, and an additional seven systems have indicated that this feature could easily be included.

Up to 100 Class-of-Service Marks

Thirteen systems are indicated to have this capability either available, or in service. One system is indicated to have this feature easily included. Typically, systems either incorporate 64 or 128 class of service marks, roughly. Some smaller systems only have 24. It is quite difficult to extend the number of class-of-service markings, since typically this is closely tied to the word size of the processor employed.

Zone Restrictions

We interpret this feature to be something similar to toll restrictions, and that calls can only be made to specific outgoing trunks identified to the system.

Basically this bars area code access by subscribers. Sixteen systems are indicated to have this feature in service or available. An additional two systems are indicated to have this feature easily incorporated. Only the DIMENSION system is indicated to be difficult to incorporate this feature.

Circuit Switching of Data

On the solid state analog matrix technology switches, this feature would only require a different subscriber line interface to permit data to be passed in this nature. Any data rate in any format up through 64 kilobits per second could easily be passed through this type of switching matrix. T&N, with its PAM switching matrix indicates that this could be easily accomplished for data speeds up to 64 kilobits per second. On the other hand, the DIMENSION PBX indicates that this would be difficult to accomplish. PCM matrix systems typically can accept a maximum of 64 kilobits per second, or lower speeds, utilizing bit-stuffing techniques. It would appear that the pulse width modulation systems can also pass data up to 64 kilobits, at least for DANRAY system. CHESTEL indicates that it is easily included in their PWM system.

This feature is available or in service on ten systems, and is easily incorporated in an additional three systems.

Numbering Plan

This feature is available or in service in 16 systems. It is easy to include in one additional system, and difficult to include on one small PABX system from GTE.

With regard to the maximum number of digits handled in the dialing sequence for the system, there is a major difference here between PABX systems and central office systems. Typically, PABX systems provide either three, four, or five digits of subscriber-dialed number decoding. On the other hand, central office systems typically provide decoding for 13 to 16 digits. We believe, however, that it would be relatively easy for PABX systems to accept a larger number of incoming digits, and to use a table look-up technique to convert this to the appropriate internal dial code for its internal subscribers.

On the outgoing side, clearly the PABX subscriber can dial any number of digits.

Alternative Automatic Routing Options

The range of capabilities here is from one to an unlimited amount. Only the small GTE GTD-120 PABX system has one alternative routing capability, whereas the typical system has a maximum of 4 to 5 alternate routings. Typically, the alternate routing capability is under software control, limited only by the number of trunk groups. It could be easily extended to included whatever amount of memory the military customer wished to devote to such alternative routing schemes.

2. Commercial Subscriber Features

Most of the PABX systems manufacturered in North America incorporate nearly all of the standard PABX features included in our survey, with the exception of malicious call handling, emergency number, and do not disturb. The smaller PABX's typically do not include automatic identification of outward dialing, and direct inward dialing. The very small units typically also do not include the various forms of call forwarding, call diversion, etc.

3. System Features

International Direct Dial

This capability is available in all systems with the exception of two PABX's and COLLINS.

Automatic Number Identification

This capability is available or in service in fourteen systems, and is not available with the remaining systems. Typically the smaller PABX systems do not include ANI, but all larger systems do.

Individual Toll Ticketing

This system feature is available with twelve of the switching systems.

Automatic Message Accounting

This feature is in service or available with fifteen switching systems in this survey, all of which allow a fully assembled format for the message accounting data. Twelve systems allow this information to be transmitted to a remote location via data link.

4. Test, Diagnosis, and Traffic Statistics

Mode of Communications for Reporting and Remote Operation

A dedicated channel is utilized for these purposes in fifteen of the systems surveyed. The use of a common channel interoffice signalling approach is available in only four systems. Sixteen systems utilize the transmission of this information in digital form utilizing a modem, and a standard voice channel between the local central office, and the centralized maintenance location.

Automatic Fault Detection and Automatic Fault Isolation

All systems but the smallest PBX's have automatic fault detection. All but two small PABX systems also have automatic fault isolation on a local basis. Most of the systems provide for the remoting of fault detection and fault isolation capabilities, and we believe that those that do not indicate that they have this capability could easily incorporate this if desired.

Automatic Subscriber Loop and Trunk Testing

Most of the central office systems include both of these capabilities, but PABX systems typically do not include these capability.

Changes of Parameters and Program

All systems permit the local change of both program and central office parameters. This is also true for the remote change of program and system parameters, with the exception of the small PABX systems from GTE and T&N.

Local Test Desk

All manufacturers claim to have this feature available in their system with the exception of the DIMENSION, the SIEMENS PABX, and the small GTE PABX. We assume that for the small PABX's that a portable test kit is provided to the maintenance person which is carried from site to site.

5. Traffic Supervision

100% Traffic Analysis

This capability is available in 18 systems. It is not available in the small GTE PABX. A substantial fraction of these can report this information remotely.

Full-Time Grade-of-Service Monitoring

This capability is available only on nine of the larger systems, specifically those from NORTH ELECTRIC, GTE, and STROMBERG-CARLSON. We would anticipate that it would also be available on the NORTHERN TELECOM systems in the reasonably near future.

C. ACHIEVING HIGH AVAILABILITY

Chapter VII of this report provides substantial detail on achieving high availability. This section represents only the key conclusions reached in that chapter.

It should first be noted that almost all of the systems covered in this survey are highly connectorized, and that major components can be changed quickly and have the quick-connect plugs. This means that although the system itself may not provide for redundant modules, for military applications it may be practical to simply replace major modules should they fail. This implies that the system utilized may have a sufficiently extensive fault diagnosis and fault isolation to permit such major modules to be replaced, in addition to the isolation down to the circuit board level.

Typically in PCM systems, the complex subscriber line interface cards are also easily diagnosed, and easily traded out when faulty. Assuming that the van-mounted switching system for military applications is attended, the average repair time for significant faults of this nature is likely to be extremely low, measured in minutes from the time the failure occurs.

The next major point which we would like to reiterate is that software failures are the principal source of failures in most central office switching systems today. There appears to be no practical way of ensuring software reliability except for extensive in-service operation of the system. In this context, the use of commercially proven switching equipment can provide major advantages to the military in getting modern equipment to the field quickly, and at a cost significantly lower than through its own internal developments. Software costs typically run 60 to 80% of total development costs. On a continuing procurement basis, the price associated with the allocation of software development and continuing software maintenance could well run in the 30 to 40% range of total purchase price.

The following conclusions are provided on other aspects of achieving high availability in electronic switching systems for telephone applications in quasi-military environments:

- Ceramic encapsulated components should likely be employed.
- Antifungus coating should likely be applied to circuit boards and their components, and fungus resistant connectors should be employed.
- Commercial systems provide several adequate means for providing redundant common controls, with no clear preference as to the actual system architecture which will be most effective for military applications.
- Duplicated memory busses should likely be provided within the common control subsystem.
- Depending upon the choice of matrix technologies, partial duplication of matrix sections or splitting of the matrix into several dependent subsystems would appear to provide adequate means of ensuring that high priority traffic can always be carried within the military switch.
- Line circuits for PCM systems are very complex, and likely will require sizeable spares, but will likely constitute the major source of software failures in small TDM switches. However, failure will typically only affect one subscriber.
- The use of AC asynchronous motors, or the use of DC brushless motors in small quantities will likely be fully acceptable to provide heat dissipation within the common control section of all of these systems, without sacrificing reliability. However, additional blowers for removing hot air from the van, or air conditioning will be required.
- For external power supply failure possibilities, we would recommend that the systems be provided either with battery reserve power, or uninterruptable power supply. In addition, the internal power supply to provide low voltage to the electronic components should be duplicated. Most systems provide this capability.
- Software errors are likely to constitute the major source of low availability of such systems, and the only means of counteracting this is to provide extensive in-service operation prior to deployment of such systems in sizeable quantities.

D. MULTIPLE DATA SPEEDS

The following conclusions have been reached regarding the ability of these commercial systems to cope with the need for multiple data speeds for military applications:

- Most PCM systems are capable of accepting data bit streams of up to 64 kilobits per second, but this requires a special line interface unit which is not available on most systems at this time. These systems are capable of dealing with almost any speed up to 64 kilobits per second, but if they do not have a common denominator with 64 kilobits per second, they may require an extensive line interface involving buffering. Such line interface has not been developed, but once developed, the cost should not be excessive. An alternate approach is to use bit stuffing techniques, which will be necessary in all cases of speeds lower than 64 kilobits, which also increases the cost of the line interface for handling digital data.
- Solid state analog space division switches are capable of handling any data speed up through 64 kilobits per second, with only a modest redesign of the subscriber line interface.
- For PAM-based systems, typically the bandwidth would be adequate to handle 64 kilobits per second on any channel. However, in the case of the DIMENSION PABX, apparently provisions have not been made for handling data in any form other than through an analog modem. In the case of the T&N 6030, it appears that they can handle 64 kilobits per second by inserting an eight bit into a normal PAM sample slot. The same consideration on line interface units would exist for this system, as for the PCM systems outlined above.
- Pulse width modulation systems also vary significantly in their digital traffic handling capabilities. The DANRAY switch is transparent for any digital bit stream of up to at least 64 kilobits per second in any format. CHESTEL indicates that such data speeds could easily be handled, but are not currently engineered into their system.

We would anticipate, however, that the line interface card for a PCM system or modified PAM system as described above, would be simpler than the analog subscriber line interface card. Many of the components currently exist, but to our knowledge they have not been put together in a form to be able to accept from 0 to 64 kilobits per second in a synchronous and/or asynchronous mode.

E. COMPATIBILITY OF PCM SWITCHES WITH DATA AND CVSD

We should like to submit the following observations on this topic:

- COLLINS has developed an interface system to their DTS PCM switch, which in a manner similar to a channel bank, allows the interface of single PCM encoded voice lines with the switch. This equipment is meant to support digital PCM telephones, of which they have a prototype. Transmission is by 64 Kbps digital signal, embedded in a 72 Kbps bit stream, allowing for framing, etc. Line mode is diphase. Replacing a digital card with a special analog card in this interface converts the port for an analog telephone.

  Status: interface is fully designed, will accept order if volume is right.

- COLLINS is designing CVSD compatibility for the same switch, for an unnamed customer.

  Status: not ready yet.

- NORTH ELECTRIC has designed a combination of the common control of their DSS-1 PCM switch with a solid state space division switching network for use in the NATO IVSN system. Contract is awarded. This matrix may be used together with the PCM matrix on the same common control.

- NORTH has the intention to supplement the IVSN switch with a digital CVSD matrix later. We were told that a mix of all three technologies could be supported on the same common control.

  Status: not ready, schedule not clear.

- TRW VIDAR claims their ITS system (PCM) is easily adapted to support circuit switching of data at 64 Kbps. It is not completely clear whether they have an interface available for this purpose or will design one. However, it appears that their D2 data terminal, which interfaces with T1 lines, can either be used or easily adapted for this purpose.

F. MAJOR PROBLEM AREAS IDENTIFIED

In general, we should like to make the following observations as to where the major problem areas may exist in attempting to accept or modify commercial telephone switching equipment to meet minimum military standards:

- o The cost and delay in obtaining proven hardware for military system and subscriber features may be extensive.

- o The problems associated with conferencing CVSD subscribers with any other subscribers and/or CVSD subscribers is a major hurdle in any system, including existing military systems.

- o The clear direction in public central office switching is toward PCM, whereas there is an apparent trend in small PABX systems toward the use of solid state analog. PAM systems appear to be serving the medium and large-scale PABX systems well. These directions appear to be moving opposite to many of the decisions which have been made concerning the military communication networks, which will lead to significant compatability and reconstitution problems utilizing commercial components and/or commercial networks.

IV

TECHNICAL PROBLEMS IN DESIGNING A DIGITAL SWITCH FOR LOCAL OFFICES AND SOLUTION APPROACHES

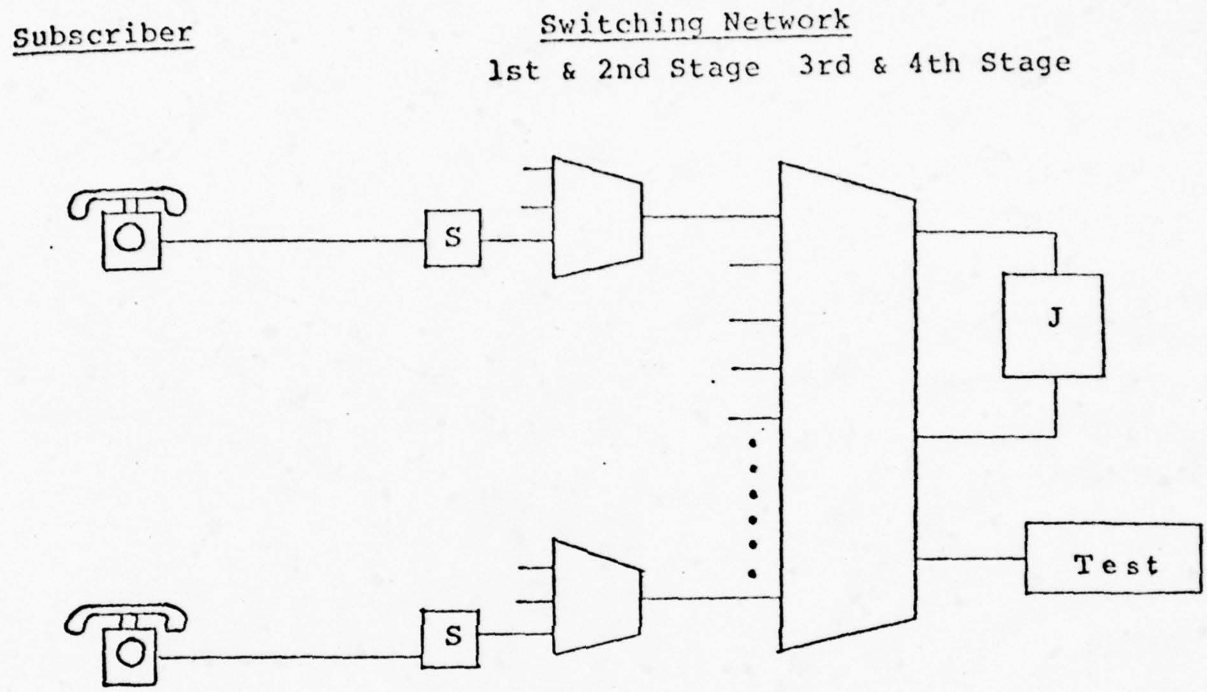
The designer of a time division multiplexed PCM switch (especially for the local environment) encounters a series of new and specific technical problems. They are new insofar as they do not occur in an electromechanical space-division switching network. The ultimate success of a newly designed PCM switch literally depends on the ability of the design team to find solutions--which are both technically sound and cost-effective--to each of these problems.

These technical problems are summarized within the acronym, "BORSCHT," which stands for:

- o <u>B</u>attery feed
- o <u>O</u>vervoltage protection
- o <u>R</u>inging
- o <u>S</u>ynchronization (or Supervision)
- o <u>C</u>ODEC
- o <u>H</u>ybrid
- o <u>T</u>est access

A. INTRODUCTION

In order to understand the importance of the "BORSCHT" problems, we have to review the basic differences between a conventional electromechanical space division switch and a time division multiplex PCM switch. Figure IV-1 and IV-2 are simplified block diagrams of these switches. The electromechanical office, Figure IV-1, establishes a metallic path between two subscribers on an inter-office or local call. This configuration permits the application of battery feed and ringing, and performs certain supervisory functions at the junctor portion of the switch. The quantity of equipment necessary to perform these functions is equal to the number of <u>junctors</u>, and



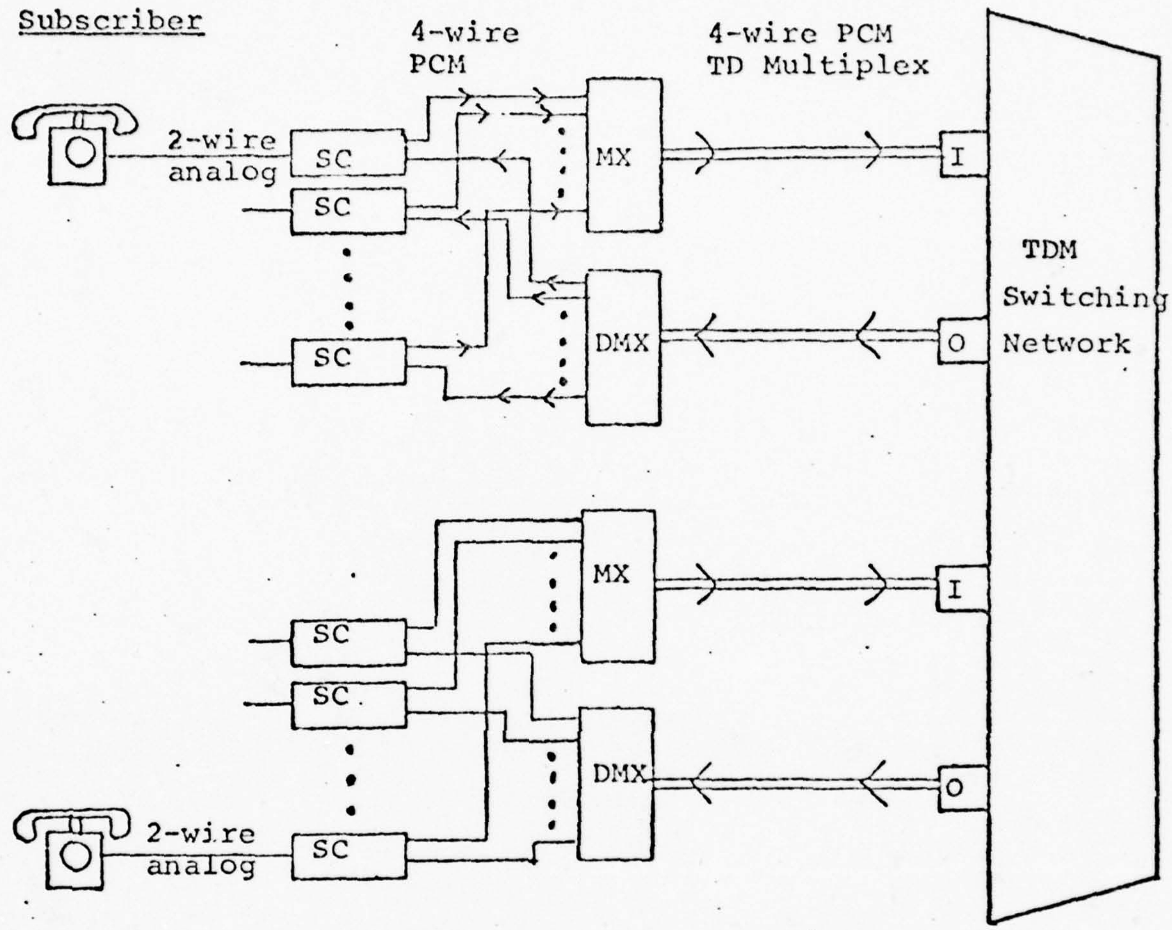
S: Supervision for off-hook condition

J: Junctor with ciruitry for battery feed, supervision and ringing

Test: Test trunk with measuring equipment

Figure IV-1

Block Diagram of Space Division Multiplex Switch



SC: Subscriber Circuits
MX: PCM Multiplexing Circuit
DMX: PCM De-multiplexing Circuit
I: Input Port of Switching Network
O: Output Port of Switching Network

Figure IV-2

therefore, about an order of magnitude smaller than the number of subscribers.

Test access to the subscriber lines is also established in an electromechanical system by using the switching matrix to make a metallic connection between the particular subscriber line and a special test trunk. Only a very small number of test trunks is sufficient for this purpose. There are some functions in such a system which have to be performed on each individual subscriber line, particularly the detection of a subscriber who goes off-hook. However, relatively inexpensive equipment can perform this function.

In a typical time division multiplexed PCM system, Figure IV-2, no metallic path is established to the switching network. Instead, each subscriber line is interfaced with the switching network to a special subscriber circuit. This circuit performs the follow functions:

- o Separates the audio signals from the D.C. signals of the subscriber line.
- o Converts from two-wire to four-wire (all time division multiplexed PCM switching systems are of the four-wire type).
- o Converts the audio signals going towards the switching network into pulse code modulation, using the proper conversion and companding algorithm.
- o Converts the PCM signals arriving from the switching network into analog signals, using the proper conversion and companding algorithm.

These circuit functions therefore eliminate the possibility in such a system to apply battery feed and ringing to the switching network. This must be done at the subscriber circuit on a per subscriber basis. Also most supervisory functions, not only detection of the off-hook condition, have to be performed at the subscriber circuit level. This includes the on-hook/off-hook condition, as well as detection of dial pulses. Only touch tone dial signals from a subscriber may be sent through the switching network, after being encoded in PCM, and then detected in the touch tone receiver.

Proper maintenance of a local switch requires testing of the subscriber lines. Metallic test access in an electromechanical system is not possible in a PCM switching network. The only way to provide such test access is through metallic contacts at the subscriber circuit level. This requires additional relays to provide such access.

Overvoltage protection is a very important feature in any telephone switching system. Traditional methods have been developed to deal with overvoltages in electromechanical offices. Electronic components, however, as used in PCM subscriber circuits, are inherently more sensitive to even slight overvoltages compared with relays and other electromechanical components. Therefore, special design efforts are required in PCM subscriber circuits to deal with this problem.

We may conclude that for the sake of the acronym "BORSCHT," three classes of problems have been lumped together:

- o CODEC and hybrid are genuine PCM system components not found in any other type of technology.
- o Battery feed, ringing, supervision and test access, because of the particular nature of a PCM switch, have to be performed in new and unusual ways.
- o Overvoltage protection becomes more critical than it is in conventional electromechanical switches. This is due to the problems arising from interfacing electronic components with subscriber lines.

From the above brief discussion, it can be seen that all of these problems influence the design of the subscriber line circuit of the local time division multiplex PCM switch. It has been shown over and over that the state-of-the-art of electronic engineering permits a solution to all of these problems. The difficulty, however, lies in whether a cost-effective solution can be found, i.e., a solution that meets all the necessary quality criteria at an acceptable cost. In order to emphasize this point, we only have to remind the reader that in a typical PCM local office, some 70% of the

hardware component cost is required for the subscriber line interface circuits. Any cost-saving design improvements in the individual subscriber line circuits will be of the greatest significance, because they can be multiplied by the number of subscriber lines served by the switch.

1. Subscriber Lines Versus Related Problems

So far, we have only addressed the subscriber lines on a local switch. This is indeed the main area of impact of the "BORSCHT" range of design problems. However, related problems occur when analog trunks interface with other local switches, and the toll or tandem switch. (No such problem exists when digital trunks are interfaced with either a local or a tandem switch.) In many cases, a number of individual analog trunks are interfaced with a time division multiplexed PCM port on the switching network, using standard transmission equipment (channel banks), available off-the-shelf from many manufacturers. On some local switches, however, special individual trunk interface circuit cards are used. They differ from the subscriber line circuits, not so much in the conversion between analog and digital format, but mainly in the type of supervision which is being performed.

The number of trunks on a local switch, however, is roughly an order of magnitude smaller than the number of subscriber lines. Further, a trunk carries a much higher average traffic than a subscriber line. Therefore, the cost of such trunk circuits does not influence the cost of the total switch to the same degree as the subscriber line circuits. This of course means less pressure on the circuit designer to arrive at the least expensive solution. It may possibly allow a compromise towards more reliable, high performance circuits without noticeable cost increases for the whole system. For these and other reasons, we will concern ourselves in this report primarily with the subscriber line circuits.

2. Discussion of BORSCHT Problem Solutions

In order to report on the various existing design approaches to PCM subscriber circuits, we interviewed seven American telephone equipment manufacturers, who either are offering PCM systems, have announced such systems, or are expected to announce such systems shortly. In this article mentioned in later sections, we will identify these seven manufacturers only by the letters "A" through "G."

We further conducted interviews with various component manufacturers, particularly semiconductor houses. We will refer to the component designs resulting from these interviews when discussing the individual problems to which they apply. Finally, in a later section, we will report the results of interviews with some European telephone manufacturers in order to illustrate the slightly different opinions and application philosophies in Europe which has led to different subscriber circuit design concepts. In the final chapter, we will present an outlook on the direction in which the state-of-the-art will likely develop within the next five years or more.

3. Design Considerations for Subscriber Line Circuits

No comprehensive set of specifications for time division multiplexed PCM switches are in existance as of yet. The CCITT is working on such a set of specifications; however, the general consensus seems to be that this is a slow and tedious process which would not be completed in time to guide the development of the present generation of PCM switches. On the other hand, certain telephone administrations apparently have developed specifications, sometimes tentative, which describes what they expect to buy in the future. In the case of AT&T such specifications (at least in preliminary form) exist, and can be expected not only to influence what Western Electric will manufacture and what the Bell operating companies will install, but also the mechanism of the domestic marketplace. It will, in particular, influence the recommendations of USITA and hence, the design concepts of independent telephone manufacturers.

U.S. Considerations

In December, 1976 representatives of AT&T explained their proposed standards for PCM switches and particularly their ideas for a loss plan for PCM switches and networks at a meeting of the United States Independent Telephone Association (USITA). Many observers of this meeting were obviously surprised by AT&T's idea to move towards a zero db loss PCM network. Although the zero db loss goal for trunk calls is not to be implemented immediately, the plan calls for zero to minus 0.5 db loss on all intra-local calls. This figure, combined with the requirement of at least 6 db singing margin was considered to be of considerable influence on the design of PCM subscriber circuits.

A second source of specifications for PCM switches will be the Rural Electrification Agency (REA), which is part of the U.S. Department of Agriculture. These specifications are formulated to guide REA when evaluating loans for expansion of rural telephone systems. However, they are expected to have a more far-reaching effect on the industry. Since they are not complete, it is difficult to make any judgments at this time.

PTT Considerations

Several foreign PTT administrations have with their own set of specifications for PCM switches. One example, in particular, is France where the government-owned PTT has, through CNET (their research and development institute), developed a set of specifications as well as prototypes of local PCM switches.

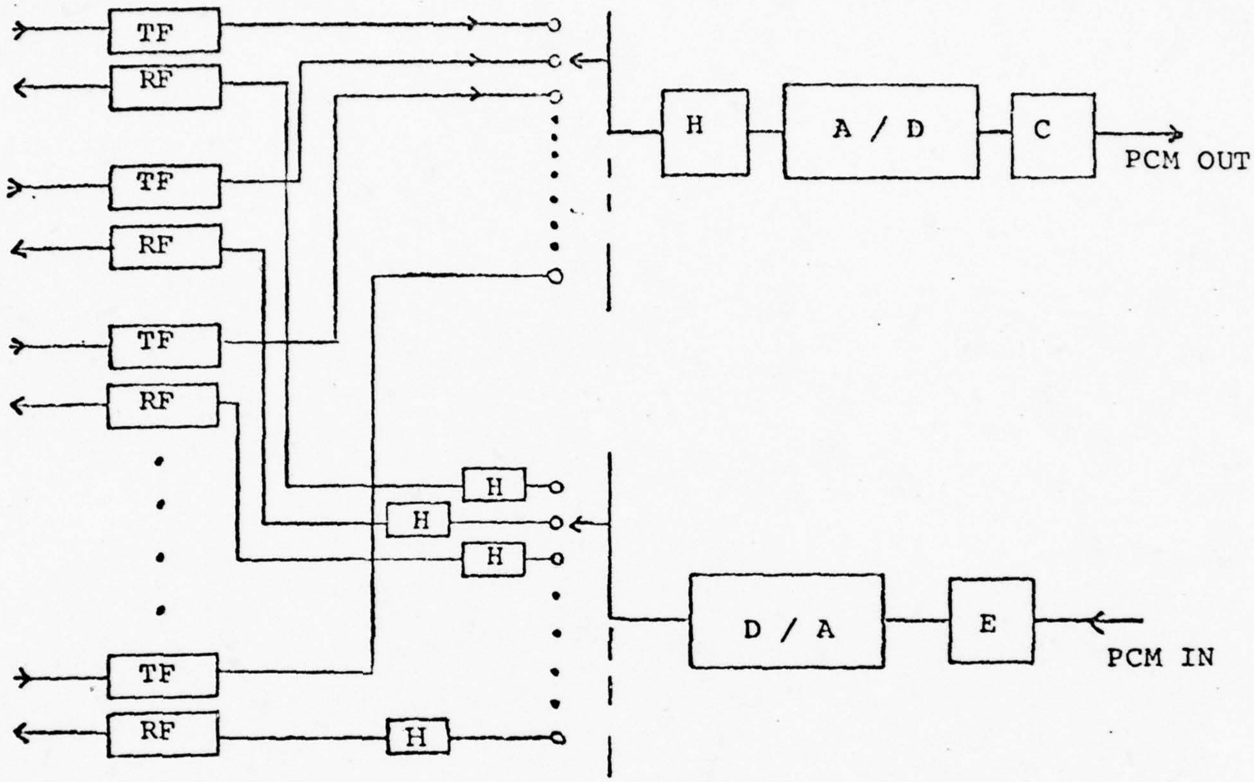
CNET has developed two essentially different approaches to the PCM subscriber circuit. In the first approach, the circuit shown in Figure IV-4 is connected with a subscriber line at all times. A digital preconcentrator stage is inserted between the PCM output and the main switching network. A different approach was taken in the design of most of the existing

installations of the French E-10 PCM switch. Here, a small reed relay matrix serves as a space division concentrator between 512 subscriber lines and 60 PCM subscriber circuits similar to those shown in Figure IV-3. We believe that this approach was selected because of the state-of-the-art at the time the E-10 was developed. (The E-10 has been in service for many years and was the first time division multiplex PCM system to go into commercial service.) We received indications that the subscriber line interfaces in all existing E-10 systems will be replaced with a new circuit design similar to the general outline shown in Figure IV-4. Although other foreign PTT administrations also seem to favor the idea of electromechanical preconcentrators, we have not encountered any American manufacturers who favor this concept. In the following sections we will limit ourselves to discussions of subscriber line circuits without electromechanical preconcentrators.

B. CODEC

The word CODEC is derived from Coder/Decoder and is generally used for the circuit element which performs the analog to digital as well as the digital to analog conversion. This also usually includes the compression/expansion which is required by the applicable conversion standard. (There are two generally accepted conversion standards, the North American and the European standard.)

Two filters are required with the CODEC for proper operation. On the analog input side, a transmit filter is necessary to limit the pass band of the analog signal in accordance with certain specifications derived from sampling theory. On the analog output side, a second low pass filter is required to smooth out the staircaselike output wave form of the digital to analog conversion. Technically, these two filters constitute an essential part of the CODEC. In present day common usage,



H

TF: Transmit Filter

RF: Receive Filter

H: Hold Circuit

A/D: Analog-to-Digital Converter

D/A: Digital-to-Analog Converter

C: Compressor Circuit

E: Expander Circuit

Figure IV-3

CODEC - Shared by 24 Lines

however, the word CODEC usually refers only to the part of the circuit which does not include the filters. We will discuss the filters in a later section.

1. Time-Shared CODEC versus CODEC-Per-Line

There are several ways to implement the function of a CODEC. Standard integrated circuits of the more common logic families allow the implementation of a reasonably fast CODEC which is relatively complicated. On the other hand, they are fast enough to be time shared by 24 or more subscriber lines. Figure IV-3 shows such an implementation of the time-shared CODEC. Sampling gates sample the amplitude of each subscriber line 8,000 times per second, which amounts to 192,000 samples per second for 24 subscriber lines. The resulting pulse amplitude modulation (PAM) pulse stream is then fed to the CODEC. The CODEC converts each individual sample into an 8-bit parallel output word. In the other direction, the CODEC accepts 8-bit parallel digital words, converts each one into the proper pulse amplitude, which is then converted to analog and fed through to gates to the proper subscriber line.

Figure IV-4 shows the other type of arrangement--where each subscriber line has its own CODEC. The transmit portion samples the filtered audio wave form 8,000 times per second and converts each sample to the appropriate digital word. The receiver portion converts 8,000 bit digital words per second back into analog voltages. The receive filter smoothes the resulting staircase wave to the best possible approximation of the originally encoded audio signal.

Advantages and Disadvantages

There are advantages and disadvantages to both approaches. While the "CODEC per line" approach requires only processing of 8,000 samples per second and per direction, the time-shared CODEC has to be fast enough to process 24 times 8,000, equal to 192,000 samples per second. In the past, most CODEC's have

been built from off-the-shelf integrated circuits, TTL technology, for the digital portion and conventional analog circuits for the remainder. Such technology, if properly applied, usually allows for operation at the speed required for the time-shared arrangement. Because of the complexity of the circuits, this type of CODEC is much too expensive to be used in the second approach (one CODEC per line). Substitution of custom-made integrated circuits for some of the functions will help to reduce the price somewhat, but not by a factor of 24, which is required to make a one-CODEC-per-line economically feasible.

Several semiconductor manufacturers, as well as some of the telephone equipment manufacturers, are currently developing monolithic CODEC's. Some of these planned products will consist of one single chip which performs both the encoding and the decoding function. Others will have a chip set, usually consisting of two chips. Most of the large semiconductor houses have either announced such monolithic CODEC's or are known to be designing such products.

It is our estimate that a time-shared CODEC, built with current state-of-the-art components, can be manufactured for about $120, or $5 per subscriber line. This cost includes the printed circuit (PC) board but excludes the necessary filters. A monolithic chip or chip set to be used as a CODEC-per-line has to be less than $5 in order to compete with the time-shared arrangement. One reason is that the latter already generates a time division multiplex output signal, whereas additional circuitry is necessary for this purpose in the case of the CODEC-per-line approach. Further, packaging costs have to be added to the price of the monolithic chip or chip set.

It is very difficult today to obtain any reliable pricing information for monolithic CODEC chips which are supposed to

become available very shortly. However, all of the semiconductor houses which have announced such chips maintain that they will be competitive with the time-shared CODEC approach, whenever they become available in volume production quantities. In our opinion, this means that they must not cost more than between $3 and $4.

If we assume that the CODEC-per-line and the time-shared CODEC will be cost competitive within a couple of years, the question then arises if there are any technical advantages to either solution. The time-shared CODEC generates a time division multiplexed signal, where the individual subscriber lines are represented in the same sequence as they are in the intermediate PAM signal. Also, all of the 24 subscriber lines are usually present in this composite signal required to perform any desired concentrating function--either with an analog space division matrix on the subscriber line side or in a time switch on the digital side. The CODEC-per-line arrangement, however, requires, as was pointed out earlier, additional circuitry to perform the function of serializing, deserializing, multiplexing and demultiplexing of the individual digital inputs and outputs of all of the CODEC's. It is relatively easy to design this circuitry in such a way that it also performs concentrating functions. For example, it could select 48 CODEC's out of 128 or 256, and combine output signals into a time division multiplex bit stream (as well as the opposite function, demultiplexing an incoming bit stream and distributing the individual channel signals to the same group of selected CODEC's). This latter approach might have a slight cost advantage over the time-shared CODEC arrangement, requiring the concentrator action to be performed somewhere in the switching network.

Reduced crosstalk between channels is usually stated as an advantage for the CODEC-per-line solution. Any CODEC uses two sample-and-hold circuits. One is used to sample the incoming

analog signal and the other one to hold the output voltage constant between subsequent digital/analog conversions. These sample-and-hold circuits use analog semiconductor gates and capacitors to hold the analog information. Residual charges in these capacitors generate crosstalk between adjacent channels in the time-shared arrangement. It is well known that a similar approach is used in channel banks for time division multiplexed trunks. However, crosstalk in a local office is considered more serious than in transmission equipment. The theory behind this is that adjacent channels in local switches always belong to the same subscribers, and that it is very likely that these subscribers know each other, whereas in the case of transmission equipment, adjacent channels are assigned differently with each call. Although this effect is quite well known, it is usually maintained by designers of time-shared CODEC systems that careful design results in a sufficiently low degree of crosstalk.

Another point in favor of the CODEC-per-line solution is certainly reliability. The time-shared CODEC in most cases consists of a much larger number of components, including more solder joints, etc. and is likely to be, at the least, not more reliable than a monolithic CODEC. However, any component failure in a time-shared CODEC will put 24 subscribers out of service, as compared with one subscriber in the case of the monolithic CODEC.

Of the seven U.S. manufactuers we interviewed, only manufacturers "E" and "G" are planning to use time-shared CODEC's. All the others (A,B,C,D and F) are either using CODEC's-per-line, or planning to use them in systems under development. In particular, they have either developed a monolithic CODEC in-house, or are planning to do so. "B","C", and "F" are planning to use monolithic CODEC's whenever they become available from the major semiconductor suppliers. In the meantime, they use mainly off-the-shelf integrated circuits, mixed with discrete

circuits in some custom-made elements packaged in "hybrid technology." (This term refers strictly to a high-density packaging technology which results in a small encapsulated module, roughly the size of a large integrated circuit.)

Conclusions

It appears that roughly two equally good solutions exist to the CODEC problem, with the CODEC-per-line approach dominating within a few years.

2. Filters

Filters are an essential part of the system component which performs a digital to analog and analog to digital conversion. However, customarily the term CODEC is applied to this system component minus the filters. In the case of the CODEC-per-line, each CODEC has its individual transmit and receive filter, whereas in the case of the time-shared CODEC, one set of transmit and receive filters are required per subscriber line.

Such filters have to meet very demanding specifications. These specifications are derived not only from the sampling theory but from the requirement that up to 12- or 13-digital to analog and analog to digital conversions may occur within the route of a telephone call. These conversions must occur without too much degradation in the speech quality. Only slight degradation in filter specifications would give cumulative degradation of a signal, since it would occur with each of the mentioned 12 or 13 conversions. However, it is quite possible to maintain the present filter specifications for all the transmission equipment, which would account for all but two conversions--those at both subscriber ends of the route. A certain amount of degradation in the specifications of the subscriber line receive and transmit filters would not affect the speech quality of such a telephone call to any great extent. It would, however, have a favorable effect on the overall cost of a telephone system, since these filters are required for

These technologies are likely to have a considerable impact on the cost of CODEC plus filter.

Conclusions

Filter costs will continue to dominate the total component cost of local digital switches, followed closely by the cost of CODEC's. Some improvement can be anticipated as sales volumes grow.

C. HYBRID, BATTERY FEED, SUPERVISION AND RINGING

In this section we are addressing four problems included in "BORSCHT." Because the technical solutions developed for these four problems are so interrelated, it is difficult to consider them separately.

In the introduction we explained that with any PCM telephone switch, the D.C. line voltage must be applied through the subscriber line circuit at all times. Also, provisions have to be made to apply the ringing circuit when required. Additionally, line supervision is necessary in order to continuously monitor the line for on-hook and off-hook conditions. All of these functions are also present in a conventional space division electromechanical switch (usually within the matrix); they only have to be relocated to the subscriber line circuit in a PCM switch. A function unique to the PCM switch and not normally found in other switches is the hybrid. Hybrid is the term used for that part of the subscriber line circuit which converts from the actual two-wire subscriber loop to the four-wire circuit which interfaces with the CODEC. The CODEC, as well as the switching matrix, are always designed to accept a four-wire speech path, which includes two-wires for each direction.

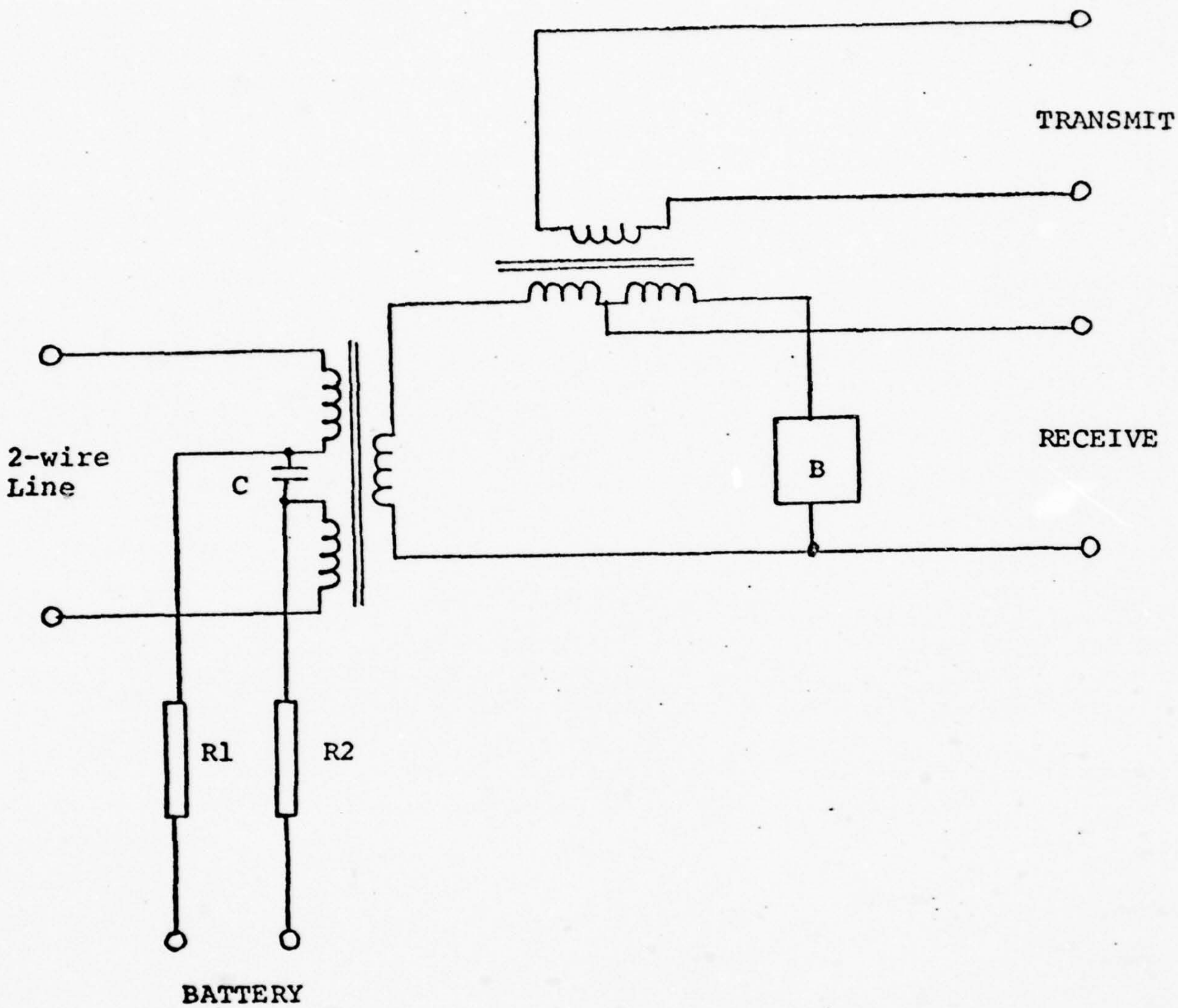
1. Hybrid

The task of the hybrid is not only to connect the two-wire subscriber loop with the transmit and the receive portion of the switch. This would be a very easy task to accomplish. A further consideration in the design of a practical hybrid circuit is to insure that speech originating at the subscriber loop should only be allowed to travel to the two wires designated for this purpose, and not to the other two wires which carry speech signals from the distant subscriber towards the subscriber loop. Also, the speech signals from the distant subscriber are supposed to reach only the subscriber at the near end and must be prevented from entering the other two

wires which would carry them back towards the distant subscriber (echo). Whenever the hybrid does not perform well enough, speech signals may travel from one end of an established call connection to the other end and back, and may cause oscillations, or at least conditions that are close to oscillations, which are called "singing." Singing will distort speech quality considerably. Such conditions also create problems of impedance matching of the various sections of the path of the telephone call.

There are certain classical ways of designing a suitable hybrid. In fact, every present-day telephone instrument contains a hybrid, which constitutes the interface between the subscriber loop on one end and the microphone and speaker on the other end. Although the design criteria for a hybrid in a PCM subscriber circuit are much more demanding than for that found in a telephone instrument, similar design approaches are possible. In fact several of the manufacturers we interviewed for this study use a classic approach, related in general principle to the one outlined in Figure IV-5. Here, transformers are used.

The primary coil of the first transformer which is split into two sections, in combination with two load resistors, allows application of the D.C. current to the subscriber loop. It also serves the purpose of eliminating common mode or longitudinal signals. The center-tapped primary coil of the second transformer essentially forms a bridge. Two of the legs of this bridge are formed by the transformed impedance of the subscriber loop and by a simplified electrical line model, consisting basically of resistors and capacitors. Whenever the line model matches the actual line impedance over the used frequency range, the transformer can be considered ideal, and the circuit acts as a 100% efficient hybrid. However, in reality, such a condition does not exist. Not only are these transformers not ideal, but the electrical parameters of a subscriber loop covers a wide range. Line lengths of between less



R1,R2: Battery Feed Resistors
B: Balancing Network (Line Model)
C: Capacitor

Figure IV-5

Battery Feed and Hybrid

than a mile and up to possibly ten miles or more might occur; cable characteristics depend on wire gauge and cable design; certain lines are coil loaded, others are not; and finally, the D.C. resistance of the telephone instrument depends on the amount of battery current in the subscriber loop, which in turn depends on the D.C. resistance of this loop. It can be seen that the "line model" in the hybrid can only be designed to meet the requirements of an average line. Subscriber line parameters that differ from this "average" condition will result in degraded performance of the hybrid. (See Section 4 for solutions.)

2. Battery Feed

There are several established design approaches for a transformer-coupled hybrid, including battery feed circuitry. Some of these approaches are similar to the one shown in Figure IV-5, others use only one or as many as three separate magnetic components. But all of them perform basically the same functions: battery feed and suppression of longitudinal signals. They further contain some sort of "bridge" in which one leg is formed by the transformed loop impedance and the other one consists of the "line model."

3. Supervision

Supervision may be performed in several ways with such a transformer-coupled hybrid. One way is to include the coil of a relay in the primary circuit of the transformer. This way an off-hook condition will activate the relay, while dial pulses will temporarily release the relay again. However, the disadvantage of relays is that inaccurate timing and contact bounce will tend to cause trouble especially when dial pulses have to be detected. A related method has been used occasionally. Here, a "reed" capsule is inserted into a hole in the transformer core, where it senses the presence or absence of magnetic flux.

Several types of non-mechanical transducers are known and have been employed for the purpose of supervision in the subscriber loop. Among these are electro-optical isolators, as well as devices which make use of the change of magnetic properties under the influence of magnetic fields, and devices using the Hall-effect. The latter type of device may be incorporated into the transformer core, sensing the magnetic field inside this core. When compared with relays, all of these non-mechanical devices have the potential of either having a changeable threshold for the detection of D.C. current, or of even measuring the current in the subscriber line and converting the amount into a digital signal. These capabilities are of advantage in certain more sophisticated subscriber line circuits as we will see below in this report.

The cost of the components necessary for such a type of circuit, in our opinion, is as follows (assuming a one-transformer circuit):

COMPONENT	PRICE RANGE
o Transformer	\$3.00 to \$4.00
o Battery Feed Resistors	\$1.00
o Line Model Components, etc.	\$1.20
o D.C. Sensor (depending on technology used)	\$1.00 to \$2.00
	\$6.20 to \$8.20

The subscriber line circuits of manufacturers "A," "B," "E," and "F" are designed essentially along these lines. Manufacturers "C," "D," and "G" indicated that they either have developed or are currently developing circuits to perform the functions outlined above which use only solid state components and <u>no</u> inductors or transformers.

From the diagram in Figure IV-5, it should <u>not</u> be concluded that the transformer is providing a D.C. isolation between the subscriber loop and the rest of the switch. One has to keep in mind that all subscriber loops are connected to a

common battery which also feeds other components in the switch. However, one of the very important functions of the transformer is the elimination of common mode or longitudinal signals. Ordinarily, transformerless input circuits, composed of transistors or other semiconductors, are sensitive to such signals or are capable of rejecting only longitudinal signals up to very few volts. The hybrid function alone, that is the conversion between the two-wire and four-wire format, is very easily performed with OP-AMPS and normal passive components. However, the inclusion of suppression of longitudinal signals, as well as battery feed and supervision, makes the design of such a circuit very involved. We have not been able to learn the details of the designs developed by the three manufacturers (C, D and G). However, it appears, that they use an elaborate network of OP-AMPS, resistors, and other passive components. While the cost of transformers and discrete passive components is likely to go up with inflation over the next couple of years, OP-AMPS might even become less expensive and, whenever they are packaged in "hybrid technology" with resistors printed on the substrate and laser trimmed to close tolerances, the resulting passive circuit components cost usually considerably less than off-the-shelf discrete resistors.

Conclusions

Without knowing the exact details of the circuits, it is difficult to estimate the cost. However, the three manufacturers which have more or less perfected such circuits think they will be price competitive with one-transformer circuits. They stated that whenever they establish volume production, they will achieve cost reductions of between 50 and 67% over transformer-coupled technology circuits.

4. Adjustable Hybrid and Subscriber Line Gain Control

As we have seen earlier, ideal performance of the hybrid requires a match between the subscriber-line impedance and the line model, which is part of the hybrid circuit. Since subscriber-line impedance may cover a wide range, depending on line length, material used, and other factors, a perfect match can only occur for a certain average subscriber line. A severe mismatch, however, will result in serious degradation of the performance of the hybrid, and thus in voice transmission quality. All of the U.S. manufacturers which have introduced PCM systems claim that they are able to meet the zero loss plan condition (mentioned in the introduction to this chapter) and still maintain the required singing margin. However, the general consensus among the manufacturers seems to be that this goal is very difficult to achieve. Two of the manufacturers interviewed are planning to overcome this basic difficulty by incorporating an adjustable hybrid into their switches within the next two or three years. Most of the other manufacturers, when asked to express their opinion, indicated that they would look very favorably at such a solution, but do not have immediate plans to incorporate this type of hybrid into their products.

Problems of an Adjustable Hybrid

The idea of an adjustable hybrid, that is to say a hybrid where the line model which is part of this circuit, can be adjusted to match exactly with the subscriber-line impedance, seems to be appealing at first glance. However, there are two problems associated with such an approach. Firstly, it is difficult to design variable resistors and/or capacitors for the required range of parameters. This can be overcome by making these parameters adjustable in steps. Thus, a reasonable match can be achieved over the entire range of subscriber-line parameters. The second problem is more serious: How to obtain the necessary parameters of the subscriber line and

actually how to adjust the hybrid accordingly. An obvious solution would be to measure each subscriber line to calculate the necessary adjustments and to perform these adjustments by manually setting a switch located at the subscriber line circuit. This, however, would be a time consuming and administratively difficult process. It further means that whenever a printed circuit board containing one or several subscriber line circuits has to be exchanged for repair purposes, the settings of these switches have to be transferred to the new board by the exchange technician. Such a procedure would mean a strict disregard of the trend towards automated maintenance and checkout procedures. Further, it would be difficult to remotely diagnose the status of adjustments to these hybrid circuits. None of the manufacturers we interviewed expressed any interest in such a design.

Possible Solutions

It appears that the only solutions to this problem which are feasible are those which perform the necessary adjustments automatically. One approach is to incorporate a digital link between the common control and each of the subscriber line circuits to store tables with the subscriber line parameters in memory, and to program the common control to adjust the circuits accordingly. However, even this approach does not appear to be flexible enough, since the outside plant is usually in a state of constant change. It would be much more desirable to actually measure the subscriber line parameters. It has been suggested that the subscriber line circuit have incorporated into it the capability to measure the D.C. current through the subscriber loop. This could be done by using a D.C. transducer for loop supervision, which not only senses the presence or absence of current, but measures the amount of current. Look-up tables within the memory of the common control computer would then contain information about the wire gauge of each subscriber line (and possibly the loading status of those

lines). Knowing the wire gauge and D.C. current allows the calculation of the length of the subscriber line and, using either a proper algorithm or another look-up table, allows the determination of the most favorable setting of the hybrid adjustment for this subscriber loop.

It is also quite possible to perform the task of measuring the subscriber line parameter and adjusting the subscriber line hybrid by adding the necessary "intelligence" in the form of a microprocessor to the subscriber line circuit. Some of the manufacturers we interviewed seem to think that prices for microprocessors and/or custom LSI elements are so low these days that such an approach will become economically feasible.

Another feature which might have to be added to the subscriber line circuit is adjustable gain, linked to the common control of the switch. This feature would allow fine tuning of the subscriber line circuit to meet the goal of a zero loss network. Further, it is also possible to compensate for attenuation in especially long subscriber lines or gather other facts for outside plant maintenance.

There are two general ways to introduce such a variable gain. An analog amplifier with remotely controllable gain could be incorporated into the hybrid circuit, or into the analog section of the CODEC, provided a separate CODEC is being used for each subscriber line. It is also possible, to build a digital attenuator into the digital interface between the CODEC and the switching network. With each of these designs, a link is required from the common control to the input of the gain-adjustment circuit in order to adjust the gain in accordance with look-up tables within the memory of the common control.

Of the manufacturers we interviewed, only one, "G," actually uses variable gain in one of their PCM systems. In this case it is an adjustable digital attenuator inserted on the digital side of a time-multiplexed CODEC. Special memory

associated with this digital attenuator is loaded with the desired attenuation for each of the associated 24 subscribers. This permits the switching of the attenuator in synchronism with the time multiplexed information from the 24 subscribers in such a way that the signal from each subscriber receives its proper attentuation.

Some of the other manufacturers indicated that they are seriously reviewing the incorporation of an analog-type of remotely adjustable attenuator into their switch at a later time.

D. RINGING

In a PCM switch, ringing cannot be applied through the switching network (matrix). It has to be applied directly to the subscriber line circuit. All of the manufacturers we contacted use a conventional relay for this purpose. This relay is usually actuated under software control through a semiconductor-type of relay driving circuit and is only employed to allow access to the subscriber line. Selecting the proper ringing signal of the correct frequency from a common ringing bus, or in some cases even generating this signal, is done with special circuitry under computer control.

It appears to be quite feasible to use semiconductor elements (TRIAC or others) to replace the relay, but as far as we know, all systems which have been announced still use relays.

E. OVERVOLTAGE PROTECTION

Overvoltage protection for all-electronic switches is much more difficult to achieve than for the commonly used electromechanical switches. Most semiconductor elements are extremely sensitive to relatively low overvoltages. However, it is generally accepted that the same specifications regarding overvoltage protection have to be applied to all equipment--all-electronic or conventional.

The most severe cases of overvoltages occur either from lightning strikes or power line crossings. Many of the American manufacturers we interviewed have initially considered the use of gas-discharge tubes instead of the common carbon blocks at the point of entrance of the subscriber line cables. However, the general consensus seems to be that gas-discharge tubes in general, and especially the two-element types, do not function very reliably and are quite expensive--while the more reliable three-element types are even more expensive. It appears that almost all of the interviewed American manufacturers are now specifying the use of a new, improved type of

carbon block overvoltage protector with their switch. European manufacturers, however, seem to have had very good experiences with the gas-discharge tubes and do not consider them too expensive. We received the impression that possibly the state-of-the-art of gas-discharge tubes in Europe are different and better than in the U.S.

In dealing with the overvoltages which are not removed by these carbon blocks or gas discharge units, the philosophy of all of the interviewed manufacturers is as follows:

- Proper design of the semiconductor circuits can result in an overall design which is affected relatively little by overvoltages. In addition, elements like VOR resistors, Zener diodes etc., are commonly used on the printed circuit boards. Also, narrow spacing of conductors in specified parts of the back plane or printed circuit board is used to confine possible arcing to predetermined areas to aid in diagnosis of failures.
- Although the above described practices will handle most of the transient overvoltage conditions, severe and sustained power line crossings still can be expected to destroy a subscriber line circuit. In this case, the design of the circuit should limit the damage to the subscriber line circuits of the affected subscriber loops. Also, possible burn out of components on the subscriber circuit board under no circumstances should be allowed to start a fire. This is a difficult condition to meet, especially since the battery feed resistors will absorb a large portion of the power introduced into the subscriber line circuit by the power line crossing.

F. TEST ACCESS

In conventional space division switches, special test trunks may be connected with any subscriber line by the diagnostic programs in the common control computer. These test trunks are connected with automatic testing equipment, which performs a series of standard tests.

No such possibility exists in a PCM switch. However, it appears that most telephone companies want to perform the same type of test on the subscriber loops that they are using currently with other types of switches. All of the American manufacturers we interviewed indicated that they will provide a metallic access to the subscriber loop in their first generation of PCM systems.

This access is achieved in one of two ways. The first is to incorporate an additional relay into the subscriber line circuit which allows the disconnection of the subscriber loop from the subscriber line circuit and connection to a test bus, which is common to a certain number of subscriber loops. Usually, the same relay connects the input terminals of the subscriber line circuit with another test bus, thus, allowing access to the analog side of the subscriber line circuit. The second approach is to use additional contacts on the ringing relay for test access to the subscriber loop, thus saving one relay per subscriber.

The test bus may be used in different ways. It can be connected to automatic test equipment at the site of the switch. Execution of tests may then be remotely controlled from a regional maintenance center, and the test results transmitted to this center over special digital data links. Another approach, especially suitable for small switches, is to use a special trunk with metallic continuity to directly connect the test bus with test equipment at a regional maintenance center. This approach is used by manufacturer "A" for the organization's first generation of relatively small central offices.

We inquired of all the manufacturers interviewed if they see the possibility of using A.C. methods for testing subscriber lines. (Such methods would not require metallic access to the subscriber line and would allow elimination of the relay presently used for access purposes.) Most manufacturers pointed out the difficulty of designing such test procedures and the additional difficulty of overturning present telephone operating company requirements and procedures. However, manufacturer "A" indicated that they are currently working on such a method and think that they could very well be incorporated into the next generation of PCM switches.

G. SYNCHRONIZATION

The problem of synchronizing PCM networks arises particularly when integrated switching and transmission systems are considered. An isolated PCM switch in an analog environment does not need synchronization with the network exterior to this switch.

Synchronization is usually included in the list of "BORSCHT" problems. However, it is a problem on a different level than those discussed so far, which were concerned primarily with the subscriber line circuit. Review of articles in technical publications on the synchronization of PCM networks reflects a changing attitude towards these problems. There was a flood of publications about synchronization and related problems for about five years. However, recently this flood has turned into a trickle of papers. Our investigation of this phenomenon, as well as our interviews with the American system manufacturers yielded the following status:

- Many years ago, the concept of a strictly synchronous network was promoted. Now, the opinion is that strict synchronization is neither necessary or possible. One technical reason for this change is that today's first generation of PCM switches use enough memory to store at least one frame of information for each TDM-PCM multiplex circuit. Formerly, when memory costs were much higher than they are today, design schemes for PCM switches had been suggested which require only the theoretically possible minimum of memory. The present new design principles allow quite an amount of phase jitter, as well as facilities for immediate recovery from frame slippages.

- Thus, it seems to be technically feasible to operate the present generation of PCM switches, even in an all-digital environment, without synchronization with the PCM transmission network. The result would be a few single frame slippages within the duration of a normal call, which would be hardly noticeable in normal conversation. Such frame slippages, however, may disturb transmission of digital data or modem signals.

- In the U.S., the Bell System has worked out a concept whereby the whole country is divided into districts, each of which will have a master clock of high accuracy synchronizing a network of distributing lines and slave clocks. This network finally synchronizes the clocks which are part of each individual switch. Without going into the details of this planned network, we would like to emphasize that even this scheme does not require a fully rigid phase relationship of all the clocks involved. It allows a certain amount of phase jitter and for occasional frame slippages.

Each of the manufacturers interviewed indicated that the first phase of the introduction of PCM digital switches, they will have to work in an analog environment, where no synchronization with any network is required. In the long run, the manufacturers expect that their customers, usually the independent telephone companies in the U.S., will enter the scheme of synchronization promoted by AT&T and the manufacturers have designed their switches accordingly.

H. THE EUROPEAN SCENE

We spoke with several European telephone switching manufacturers. In France, the French PTT administration, through their research facility CNET, has developed the E10 system. This was the first PCM local switch to be introduced into any public network. We also spoke with TELEFONBAU UND NORMALZEIT (T&N) in Frankfurt, Germany, which manufactures an all-electronic PABX, the Model 6030. Although this PABX uses PAM technology, a PCM version has been developed and sold overseas for PABX and central office applications. We also had discussions with several manufacturers, including Philips and Siemens, who do not presently offer PCM switches, but who nevertheless gave us valuable insights into the thinking of the European PTT administrations and manufacturers with regards to PCM technology.

1. French E10 System

The E10 system is a small local switch using PCM techniques (initially up to 10,000 lines). It has been developed by CNET, and is manufactured by CIT-ALCATEL and other manufacturers.

The E10 system has been in service for a number of years, and the original hardware reflects the state-of-the-art at the time of development. However, new hardware has been designed in the meantime to be retrofitted into the systems in service. As far as subscriber circuits are concerned, most of the systems are equipped with subscriber circuits of the type called CSA. CSA consists of time-shared CODEC's and associated circuitry reflecting the state-of-the-art of the late 1960's. It includes a space division preconcentrator stage using reed relays.

Recently, CNET has introduced the new version of the subscriber line circuit called EMA. It does not use analog preconcentration. The difference is that one time-shared CODEC

serves 30 subscriber lines instead of 24, following the European standard.

The EMA uses a simple transformer between the subscriber loop and the subscriber circuit. It is relatively small and consists of only two coils. It also serves as an inductor for battery feed. The function of the hybrid and the transmit and receive filters are entirely implemented in semiconductor technology and form a relatively small plastic encapsulated building block. It was explained that relaxed filter specifications (from those commonly required for transmission type equipment) are being used in the transmit and receive filter of the EMA. This apparently is an approach different from that used by all of the American manufacturers. As explained earlier (in the filter section B.2), such an approach is completely feasible, but it appears to be questionable whether the American market would accept these degraded filter specifications. However, as a result of relaxing the specifications, the function of the hybrid (without battery feed and supervision), as well as both filters, could be implemented using only five OP-AMPS. Further, CNET received quotes for the packaged circuit from several major U.S. semiconductor houses for between \$6 and \$8 in production volume, which means a substantial cost reduction over the design approach taken by most other manufacturers.

Overvoltage Protection

In France, the installation of gas-discharge tubes on all incoming lines is generally assumed. Further special Zener diodes and special break points are used on the subscriber line printed circuit boards themselves.

2. TELEFONBAU UND NORMALZEIT PCM Version of the 6030 System

T&N has developed a PCM version of their 6030 PABX which is also to be used as a small central office. Some interesting features of this system are highlighted below:

CODEC

T&N uses a time-shared CODEC in their system built from off-the-shelf semiconductor components. They explained that right now they do not see the possibility of obtaining one-chip CODEC's, and that such technology is regarded as transitional anyhow. They explained that CODEC and filters will be integrated in a common monolithic circuit at a later time.

Hybrid, Battery Feed and Ringing

T&N uses a relatively unique approach for this part of the line circuit. One transformer is used for D.C. isolation, and two separate small inductors for battery feed. The hybrid itself, meaning the circuit that actually converts between two-wire and four-wire, is a separate all-semiconductor component. The battery feed circuit, in addition to the two inductors, uses a specially designed semiconductor chip acting as a constant-current source. T&N explained that with the European-type of telephone instrument, which does not use non-linear D.C. resistors, a constant-current source means a very valuable improvement of the properties of the subscriber loop.

Filters

T&N explained that they have spent considerable time evaluating all possible state-of-the-art technologies suitable for filter implementation and finally arrived at filters which are built entirely from passive components. They found that filters implemented with OP-AMPS and laser trimmed resistors packaged in "hybrid technology" would be more expensive. However, this approach is only possible because T&N used an active electronic circuit as a hybrid, which allows the introduction of positive gain to compensate for loss in the passive filters.

Test Access

T&N is using a relay to gain metallic test access to the subscriber circuit. However, they think in the future a non-D.C. type of test procedure, which would not require metallic

In the following sections, we will discuss a few topics that appear to be viewed differently from that found in the U.S.

Synchronization

The same design philosophy for the switch is found in Europe and the U.S. This means there is enough storage provided for a full frame of PCM. Circuits are incorporated into the switch which allows the synchronization of the local clock with any other clock, accommodating a certain amount of phase jitter.

However, contrary to the prevailing opinion in the U.S., every manufacturer we interviewed stated the following:

- No European standard for PCM systems has been established so far.
- The CCITT is working on standards. However, it might be a long time before the standards become available, and they often tend to be unrealistic and difficult to apply.
- Using a quartz crystal as a local clock, which costs well below $100, will reduce frame slippages to only a very few per duration of an average call. Such frame slippages are barely audible. Unless digital data are transmitted over an integrated switch and transmission network, no synchronization is needed.
- Synchronization is also a political problem. It is likely that none of the major European countries would like their telephone network to be synchronized by another European country.

Subscriber Loops

Although the existing PCM switches have been designed to accept subscriber loops with a D.C. resistance of 1300 to 1600 ohms, there seems to be a different philosophy with regard to subscriber loops in Europe. Firstly, the European telephone instrument does not use non-linear D.C. resistors. Secondly, it is usually explained that there is a much lower incidence of very long subscriber loops compared with the United States.

This is certainly due to the much denser population in Europe. It was also stated that PTT administrations are more inclined to install special low-current (electronic) telephones for subscribers with particularly long loops. Such telephone instruments seem to include advanced principles for ringing.

Loss Plan

No comprehensive European loss plan applicable to PCM systems exists so far. In countries like Holland, where an overall zero db loss plan for existing analog telephone system has been achieved, we were told that the PTT will most likely keep the zero loss properties of the telephone network even if PCM was installed at a later time. However, most people we interviewed in Europe tended to view AT&T's zero loss plan for a PCM telephone network as some kind of attempt to intimidate the U.S. independent telephone companies. No one could think of a reason why a loss of between -2 db and -6 db on intra-local calls should not be tolerable or even beneficial.

I. OVERALL CONCLUSIONS

After interviews with technical management personnel of nine firms developing local PCM switching systems, we have concluded that:

- Acceptable cost-effective solutions exist to all the BORSCHT problems, and these solutions will become more cost-effective with time.
- The first-generation of PCM local switches will not incorporate the most advanced solutions now visible for each of these problems.
- The lack of recognized standards for PCM switching (local) will slow acceptance of such systems in some countries.
- More experimentation with actual user acceptance of different standards will likely be required before an international standard is feasible.
- The R&D commitment to all-electronic PCM local central office switching technology vitually assures that this technology will be the next major thrust in local switching--and likely sooner than expected by most observers.

V

SOFTWARE CONSIDERATIONS

This area was not given primary focus during the course of this current contractual effort. It appeared that the major focus should be on the hardware problems associated with electronic switching systems applied for military use, in order to initially discover the major limitations in those areas. We now have a fairly complete understanding of the hardware problems, and could more effectively address the software considerations in adapting a commercial electronic switching system to military applications. We are proposing additional study effort in this area.

Provided below are observations and conclusions relating to the relative ease or difficulty of modifying or extending the existing software of commercially available electronic switching systems to meet a minimal set of military requirements.

A. SPECIAL SUBSCRIBER FEATURES

Most of the commercial switches surveyed already included a comprehensive set of "standard" subscriber features in their software. To a large extent, these subscriber features are implemented in software, with little hardware interaction, other than to require additional memory both for the feature program, as well as for feature data storage required for features such as abbreviated dialing, call forwarding, etc. In general, most of the common control processors have the ability to accept sufficient memory within the addressing structure, and within the basic physical frame to implement both commercial and special military subscriber features without unusual costs being incurred. The feature of "call waiting" requires hardware as well as software embodiment, in order to apply the special call waiting tone to the called subscriber line.

<u>Military Call Precedence</u>

The software embodiment of this capability has been indicated to be either available, or easily implemented on most of these

commercial systems. However, we should like to point out that there are several concepts as to how this feature is implemented-- particularly with regards to the immidiacy of the priority given to higher precedence calls. Specifically, it is our belief that few of these system manufacturers who indicated current availability or easy implementation anticipate providing the facility to interrupt the call set-up processing for lower precedence calls to accept a higher precedence call. We anticipate the same is true if the processor is engaged in the "knock down" of a lower precedence call. Rather, the processor would wait until either the call setup or knock-down were complete, then process the higher precedence call. This might be a delay measured in the range of 10 to 30 milliseconds. We believe that this delay should be fully tolerable within the military switch, since it is below the threshold of perception of the normal human being.

Typically, the commercial switches may contain too many subscriber features to provide the greatest economy in the use of memory in the common control, as well as to achieve maximum reliability. For this reason, the program for the commercial switch should likely be modified to specifically take out these allocations of software for unneeded features, in order to avoid their inadvertent use, and subsequent confusion or lack of ability to use the telephone in the normal mode.

The secure mode/key conversion requires both hardware and software modifications which have not yet been studied in any depth.

B. SPECIAL SYSTEM FEATURES

The major consideration here is the ability to provide remote operation and maintenance features, as well as interface with a variety of signalling systems. Nearly all of the new central office switching systems provide this in their standard commercial version, whereas the commercial PABX systems do not. Typically, we do not consider it difficult to provide such remote indications of maintenance functions, requiring at most in the range of 1,000 to 2,000 words to implement. The ability for remote operation, such as to provide the ability for number reassignments, would likely require at most 50% more memory.

The ability for handling other signalling systems, specifically those with a compelled sequence during the handshake operation will require a substantial amount of memory and software development to implement. We could visualize several thousand words of program memory being allocated to each signalling system utilizing a compelled signalling sequence.

C. PROGRAM MODULARITY

The ability of the basic operating program to treat major program segments as "black boxes" with specified inputs and outputs has been a desired objective in the computer field for many years. Few systems have actually achieved any significant degree of true modularity of program segments, particularly for smaller systems where one attempts to minimize the amount of memory required to implement the operating system. Our further objective of modularity is to permit the individual "black boxes" to be modified internally, without changing the input or output specification. Within this concept "without having to modify any other segment of the operating system," we doubt if it would be practical to specify full modularity in the operating system, in the switching programs, and subscriber feature programs for a procurement within the next few years. Rather, the use of a switch which is proven in the field, under a variety of conditions, likely would be adequate assurance of software integrity without the requirement for full modularity.

D. SOFTWARE DEVELOPMENT COSTS

In modern full electronic switching systems, the overall initial development costs currently are running such that 50% to 60% of the total development effort is put into software development. This is not only for the operating system, switching program and associated subscriber features, but for the necessary support programs to permit higher level languages to be employed for program modification, extensions, and parameter insertion. The development of the fault isolation and diagnostic program likely constitute at least 50% of the overall development costs. Adding a sizeable number of special military subscriber or system features which had not been visualized during the development of these fault isolation and diagnostic programs may require significant additional development costs to ensure that these are adequately monitored. On the other hand, the major concern is with the basic operation of the switch, and the identification of faulty line circuits, trunk circuits, memory modules, or processors. Thus, one may be willing to accept a less than full testing of the specialized features in the diagnostic program set. This area should be given further study.

For a small/medium size digital PABX development, total development costs are running in the range of $5 to $10 million. This means that the overall software development is likely in the range of $3 to $4 million, with the diagnostic programs being a $1.5 to $2.0 million portion.

The development costs for additional military subscriber features is likely to be at most a $1.0 million effort for those systems which already do not include some form of call precedence capability.

E. SOFTWARE RELIABILITY CONSIDERATIONS

It is in general still true that the largest source of single subscriber, multisubscriber and total system failure events are still attributable to software problems in most stored-program control systems. Typically, such faults give rise to a re-initialization of the program by reloading one or both processors from an off-line storage device. Operation experience with stored-program systems would indicate that absolutely no assurances can be given that such failures can be significantly eliminated by means other than full field experience with this system. Unfortunately, there does not appear to be any substitute for such actual field experience within the network environment in which the switch is to ultimately operate in order to identify and remove the software "bugs" from these systems.

It is important to recognize that the off-line storage devices for containing both the basic operating program, as well a number of specialized diagnostic programs held in off-line storage, constitute the major source of limitations on the humidity boundaries within which the system can effectively operate. It also has a substantially eliminating effect upon the operating temperatures, but not as significantly as upon the humidity specification requirements of the switching system.

VI

ACHIEVING SIGNALLING COMPATIBILITY

This section will deal with the results of the survey as they apply to the area of signalling both at the subscriber level and at the interoffice level. The problems associated with attempting to achieve compatibility with the wide range of signalling systems indicated to be of interest to the U.S. military will also be discussed.

A. GENERAL DISCUSSION OF SIGNALLING

1. Signalling Principles

For both subscriber lines and trunk lines, we distinguish between line signalling, consisting primarily of the transmission of on-hook and off-hook status information, of trunk seizure from one end of the trunk, and acknowledgement of the seizure from the opposing end of the trunk. Secondly, register signalling consisting primarily of the capability for the transmission of numerical information in either direction, or in both directions for call establishment, for identification of the calling party, or toll message accounting, and other administrative functions.

In-Band and Out-of-Band Signalling

For either line signalling or register signalling, the actual transmission of status or numeric information may be done either within or outside of the voice frequency band of the communication channel. In the United States in-band signalling is accomplished either with multiple frequency toll signalling for toll trunks, or the use of the normal "touch tone" dual tone multifrequency signalling approach. The signals utilized for toll signalling are substantially different from those utilized for touch tone signalling, in order to avoid abuse of the accounting facilities of the network.

In the United States, both line and trunk signalling at the central office interface are normally D.C. signalling approaches, for all lines except those utilizing carrier systems. Most carrier

systems in fact accept such D.C. line signalling and convert these to a different in-band or out-band signalling format for use within the carrier system. Thus, in general in the United States the most frequent form of line signalling is almost exclusively DC signalling with E&M or loop signalling being the preferred modes of D.C. signalling. Ground start D.C. signalling is commonly employed within PABX trunks. Register signalling is typically transmitted either with D.C. pulses, as on rotary-dial subscriber lines, or in older trunk lines. Alternatively, the signals may be transmitted using MF techniques which are always in-band.

In Europe, similar techniques are employed for both line and register signalling, but different sets of frequencies are employed. A radical difference exists between the standard CCITT R2 and R1. The R1 scheme utilizes in-band line and register signalling with the register signalling being MF pulse, whereas the R2 utilizes in-band register signalling and out-of-band line signalling, with the main difference really being the sequence of events which must occur in establishing the call.

In general, in-band MF or DTMF signalling is the easiest form to handle on modern electronic switching equipment of all technologies, because the signal can be conducted through any portion of the matrix to necessary receivers, or from senders without further processing. This applies to both toll MF and DTMF signals. All forms of D.C. signalling require a significant amount of peripheral subsystem processing prior to permitting the primary voice signal path to be established to any portion of the matrix. These peripheral subsystems consist primarily of relays together with a scanning mechanism to detect a status change to take the appropriate processing action. Thus, the use of full electronic switching systems constitute a major change in the way in which D.C. signalling systems are handled. Even in SPC reed relay systems, D.C. signals can be fed through initial portions of the matrix for decoding or pass through to subsequent offices.

The use of CCIS (Common Channel Interoffice Signalling) techniques involves the use of a separate channel for signalling between offices. The information is normally transmitted via data modems in the same manner as would be accomplished between any standard commercial computer system.

B. PROBLEMS AND POSSIBILITY IN EXTENDING THE SIGNALLING SYSTEMS HANDLED BY ALL-ELECTRONIC SWITCHING SYSTEMS

Two major items are required for incorporating a new signalling system, or extending the range of signalling systems which a given all-electronic switching system can accept. The first of these is an appropriate hardware interface which will recognize the incoming line and register signals, and allow the transmission of these signals in an appropriate form to an outgoing trunk or line. Any out-of-band signalling of either the MF or DC type forms must be inserted and detected directly at the line or trunk interface with the switching system, whereas all in-band signalling can be passed through initial stages of the switching matrix before it is processed into a standardized form or simply transmitted through the matrix entirely. Hence, to handle a new signalling system from a hardware viewpoint, a relatively simple tone receiver and transmitter in the case of in-band signals would be required, connected to the core on the matrix, and in the case of out-band signals, a different type of relay activation may be necessary, to connect an out-band signal source with an appropriate driver or scanner.

For adding CCIS to an existing switch, an additional port on the common control computer would be required to interface with a medium speed (typically 2400 bps) modem.

The second major requirement for accommodating a new signalling system to an existing all-electronic switch is to provide the necessary software interpretation of the signal sequence as received, and to generate the necessary signal sequence as appropriate for the signalling technique utilized on the outgoing side of the switch. Typically a few hundred words in storage might be required to accomplish this for both the incoming and outgoing side. Thus, in very general terms, the cost associated with adding a new signalling system to an existing electronic switching system would involve an additional line/trunk interface card which might cost in the range of $200 to $300 per line/trunk adapted to accept this signalling system. The additional memory associated with the processing

of the signalling sequence is also required which might represent an additional 400 to 500 sixteen bit words. This likely costs in the range of $30 for the basic chip, plus an additional $30 for the associated circuitry, or an additional $60 in the central processor unit.

Of course, the central processor must be capable of accepting this additional memory within the addressing structure, and of having adequate processing speed to deal with the decoding of the specialized signals. However, we would anticipate little problem with the types of processors typically employed in the systems studied in this survey.

C. SUMMARY OF SURVEY RESULTS CONCERNING SIGNALLING

At the time this analysis was conducted, we had received 16 completed questionnaires from manufacturers of all-electronic systems. Presented below are the results of these 16 systems surveyed.

Local Signalling Techniques

o D.C. Dial Signalling	16 Systems
o Touch Tone Signalling	16 Systems
o D.C. Neon Dial Signalling	0 Systems with 2 systems indicating easily implemented.
o A.C. Dial Signalling	2 Systems with 1 additional system indicating easily implemented.
o VF 2280 Hz Signalling	1 System, with one additional system easily implemented.
o VF 600/750 Hz	1 System, with one additional system easily implemented.

Interoffice Signalling

o CX	6 Systems
o DX	7 Systems
o Decadic	10 Systems
o E&M	16 Systems
o Loop-Start	16 Systems
o MF	14 Systems
o MFC	6 Systems with 1 additional system easily implemented.
o SF-2600 Hz	5 Systems
o CCITT #4	1 System
o CCITT #5	1 System
o CCITT #6	1 System
o CCITT #7	0 Systems
o PCM T1	4 Systems
o PCM CEPT	4 Systems

Interface With Other Systems

The following number of systems included in the survey indicated an ability currently to interface with the specialized systems indicated below:

- o AUTOVON 5 Systems
- o NATO 4 Systems
- o AN/TTC-38 4 Systems
- o AN/TTC-39 3 Systems
- o West German Public Network 6 Systems
- o French Public Network 6 Systems
- o Belgium Public Network 7 Systems
- o Dutch Public Network 7 Systems

In response to the question included in the survey related to international direct dialing, almost all of the small central office systems indicated an ability to accomplish this. However, we did not ask whether the necessary sequence of signals for the variety of international signalling systems could be generated. We believe that the responses relate only to the ability to generate the long sequence of digits required for international dialing.

Similarly, for those PABX systems where "direct inward dialing" is indicated, we believe that the suppliers only have this capability in those countries where their PABX systems are being actively marketed. This means that most of the U.S. suppliers do not likely have this capability in Europe. Several suppliers have indicated that they have the technical capability for such interfacing, but have not received "type approval" for such operation.

VII

ACHIEVING HIGH AVAILABILITY

The purpose of this chapter is to discuss the various means utilized by several commercial manufacturers to achieve high availability (and/or reliability) of their switching systems. We will also discuss some of the techniques utilized in more advanced military systems, and those being considered for commercial implementation.

A. COMPONENTS

The type of components utilized in commercial systems is the plastic encapsulated LSI technology, with the exception that most truly large scale integrated circuitry, particularly from memory, are not yet available in plastic. These are largely provided using a ceramic packaging, or some form of hermetic sealing. In general, plastic encapsulation is considered to be somewhat less desirable from the point of view of use at elevated temperatures, but nonetheless, over 80% of all components delivered are of the plastic encapsultated from. These components are heavily used in minicomputers, such as the PDP-8, which has operated successfully in huts near railroad tracks, and in other relatively extreme environments. However, the PDP-8 uses small- and medium-scale integrated circuit configurations, and not the true LSI technology. In general,. the very large LSI is available and utilized in new telephone switches and is largely in ceramic encapsulated form.

In general, these commercial systems are specified to operate in the range of 0° C to 50° C with the ability to operate beyond this range for short periods of time. We were unable, however, to obtain more detailed information as to how long they could operate outside this normal temperature range without adverse effects. The higher the packaging density within the system, the more rapid the heat build-up that is likely to be experienced. Here, the use of multilayered PC boards may prove a disadvantage with regards to permitting an extended range of external operating temperatures, because of its much higher power density within the PC board.

Several of the manufacturers indicated that they could easily substitute ceramic package components for the plastic encapsulated components which would not impact the temperature range significantly. It might tend to reduce the failure rate of components at elevated temperatures. This action would also extend the humidity range from that currently quoted by most commercial equipment manufacturers of 20% to 80%, to close to 100%, where there is no condensation. However, other components would likely suffer in this very high humidity environment more significantly than the semiconductor circuits. Fungus growth on connectors would be one problem, if an extended period of high humidity were encountered. Printed circuit boards might also have to be coated to prevent fungus growth to obtain an extended humidity specification.

In general, attempting to extend the environmental conditions for commercial systems to meet full military specifications typically in the range of -55^{o} C to 70^{o} C for external temperatures is likely to be extremely difficult to obtain without major redesign of these systems. However, we should like to point out that in general, such commercially designed systems do not undergo catastrophic failure at elevated temperatures, but rather suffer a substantially increased failure rate of electronic components.

B. COMMON CONTROLS

The common control portion of switching systems is the portion most significant in terms of its impact on system availability should failure occur. Almost all commercial systems surveyed include some form of redundancy in the common control section of the switching system (with the exception of some very small PABX systems).

In general, there are four modes in which redundancy is provided in the common control subsystem:

- Synchronous redundant configurations, in which two processors operate in parallel, with intermittent tests being run to determine if each processor is healthy. This also compares the outputs of each processor in a dynamic fashion to determine that both are functioning properly. When discrepancies occur on the output, special diagnostic programs are employed to determine which processor is healthy, and the output of this is utilized on a continuing basis until repair can be accomplished on a faulty processor. A slight variation on this scheme is employed in the VIDAR system, in which two sets of synchronous redundant computers are used, one set of which is normally assigned to central office administrative tasks, whereas the second set is used for switching applications. When the switching pair is found to be faulty, the functional assignments are reversed, and the administrative processor pair is utilized for the switching function. This is a relatively unique approach, and is cost effective primarily because the relatively inexpensive INTEL 8080 microprocessors are employed in this system.
- Load-sharing configurations, in which incoming calls or other switching processing functions are assigned to the processor most available to accomplish the task. Essentially this could be viewed as a random assignment of workload to the processor pair. Periodic tests are made of both processors to determine if they are healthy, and if one is found to be faulty during this test cycle, it is removed from service. The entire workload is them given to the remaining processor until such time as the faulty processor is repaired. Typically, ITT is the only major manufacturer which takes this approach, and THOMSON CSF which is based on basic ITT design concepts.

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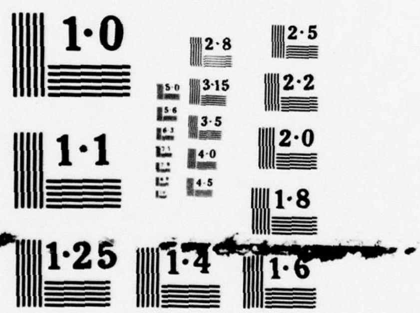

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MICROCOPY RESOLUTION TEST CHART

o <u>Multiprocessor configuration</u>, in which more than a single pair of processors is employed, with a functional specialization of each processor to specific switching tasks as they occur. Periodic test cycles are run on each multiprocessor, and the results are used to perform one of two processor assignments:

- If a synchronous redundant processor is provided with each multiprocessor unit, the alternate processor in the synchronous redundant configuration is made dominant.
- If the synchronous redundant processor is already found to be faulty, or if none is provided in the system, a lower priority computer in the multiprocessor configuration is assigned to the higher priority switching task. This tends to give "graceful degradation," and ensures the high priority switching task can always be accomplished.

There are also different configurations utilized in the main memory associated with the common control processors. In some smaller systems, duplicate memory is provided to each processor in the processor pair. In larger configurations, however, normally only one memory system is associated with each processor. In general, in these larger processors, there are three ways in which memory reliability (availability) can be enhanced:

- Error correcting bits can be added to each word of storage, to permit the processor to correct most memory errors resulting from memory element failure. This requires intermittent test of the memory for bad chips, in order to prevent memory failure at a later time when the number of bad bits increases beyond the ability of the error correcting code to deal with it.
- Parity bits can only be employed with each memory word, and relatively frequent tests made to determine if memory is fully operational. If a parity bit error is found, an additional memory card is automatically switched into the system, and the program reloaded into this memory from an off-line storage device, and the processing sequence continues. This is said to take about the same number of additional memory chips as would be required for full error correction techniques in the memory itself.

- Use of duplicated memory access buses is being considered, we understand, for the DMS 100 system. This solution may be desirable because of the serious impact which bus failure would have upon overall system availability. We believe that the STROMBERG-CARLSON series also includes a duplicated central data bus. Most of the systems surveyed include the use of at least a parity bit to determine memory failure, but several of these systems were not provided with sufficient detail to determine how this problem was solved within this system. The trend in the memory field in this area is clearly toward the use of semiconductor memory, which is proving to be both cheaper, dissipates less power, is faster and requires less space. We have learned that TEXAS INSTRUMENTS typically recommends the use of a parity bit only for up to 20K words of 16-bits each, and the use of error correcting codes when the memory size exceeds 20K 16-bit words. This is for the typical minicomputer application.

o <u>Hot standby configuration</u>, in which one processor is always active, and the second is constantly being provided with input, as in the synchronous redundant mode. Periodic tests are made of the computer in the active mode, and when some indication of failure is obtained from these tests, active control is passed to the hot standby processor. Here, the outputs of both computers are <u>not</u> constantly being compared. Although this is a simple and effective system, calls in the process of being set up or released are lost, but calls in the talking stage are not lost.

Most systems surveyed include some form of replicated interfaces between the common control, and the switching matrix. In general, the off-line essential peripheral equipment for program reload, etc. are typically duplicated in the larger configurations of commercial switching systems. This would certainly be recommended for military application. Typically, a tape cassette is utilized for such program reloading functions. There appears to be a clear trend away from the use of magnetic drums for intermediate program storage, or program overlays, particularly among North American manufacturers.

C. MATRIX REDUNDANCY

1. Solid State Space Division

Such matrix systems typically include some built in redundancy, as well as the ability to simply bypass crosspoints which are found to be defective through diagnostic analysis. Such systems can employ a map in memory, with off peak period diagnostic programs being run to identify faulty crosspoints. These are then identified in the map to avoid their use in making connections through the matrix. Neither the GTE ETSS nor the ITT TCS2 employs a duplicated matrix. In general, we would not anticipate that matrix systems of this technology will use a duplicated matrix configuration.

2. Pulse Amplitude Modulated Systems

Typically, this type of system provides a fully duplicated matrix configuration in the larger size classes. In smaller configurations, since a matrix failure typically affects only one subscriber, a fully duplicated matrix is not provided.

3. PCM Switching Matrices

In general, PCM switching matrices are not fully duplicated among the systems surveyed. Rather, there tends to be selective and differing redundant portions of the switching matrix, or access to the matrix provided. The DMS 100 system provides a redundant path between the time and space division portions of the matrix, as well as between the subscriber termination and the first stage of the time division matrix (entrance port). In the WESCOM system, four blocks of switching matrix are provided with one spare block provided which can be automatically switched in if a faulty block is found. Since this switch is a full time division switch, this concept is easier to employ than in a time-space-time matrix configuration.

One concept employed in the NORTH ELECTRIC DSS-1, is that in effect two switching matrices are provided, each with roughly 50% of the maximum traffic handling capacity of the system. Calls can be selectively routed through these two matrices by the common

control such as to allow degraded service should one entire matrix fail. This is similar to the load sharing concepts in common control utilized by ITT. This means that in military applications,. high priority traffic could always be handled in the case of the single matrix failure. Thus, with the NORTH ELECTRIC concept, no single subscriber would be affected by failure of one of the matrices. The STROMBERG-CARLSON DCO system uses a fully duplicated switching network. A special switch-over control, under supervision of a special main terminal processor, selects one matrix and one of the two call processors for call handling. In case of failure, operation is converted to the standby system. In contrast, almost all other PCM switches, with the possible exception of the NORTHERN TELECOM DMS-10, a matrix failure would likely give rise to an entire set of subscribers served by a T1 group to be lost.

It should be recognized that the reason why a number of the North American manufacturers providing essentially tandem switching equipment, have not provided a greater degree of duplication of the switching matrix. This is that typically multiple appearances from each remote central office are available on different T1 lines into the tandem office, as a basic principle of "network protective switching." This makes the loss of a single T1 group less significant in the tandem application.

D. LINE/TRUNK CIRCUITS

In almost all of the systems surveyed, there is no built in redundancy in the subscriber line circuit side of the switching system. One concept, which is reported to be under consideration for the DMS-100 system, is that of permitting, under automatic control, one subscriber line card to be taken out of service, and another spare line card inserted by routing the subscriber over the test bus to that card. This permits the subscriber to have continued service, but inhibits testing during this interim fault set-up approach.

As best we could discover from the scant literature on this subject, all of the systems in this survey did not provide for a duplication or replication of the trunk interface circuit. This is explained by the fact that typically more than one trunk route is provided, and these are normally provided on different T1 or CEPT carrier systems. If a single trunk is out, an alternate route is available to the same termination. It should be pointed out, however, that the trunk interface to a digital carrier system is extremely simple, and would have a much higher reliability than the very complex subscriber line interface to a PAM or PCM switching matrix. Similarly, on the subscriber line interface side of a solid state analog switch, the circuit is extremely simple, and would have a relatively high reliability and, hence, would not likely require duplication.

E. POWER SUPPLY

Nearly all of the systems surveyed utilize a 48 volt power supply, most with multiple D.C./D.C. converters to serve major subsystems of the switch itself. If not basically operating at 48 volts, typically a 48 volt option is provided for the system. Several of the U.S. suppliers such as ROLM, WESTERN ELECTRIC, SIEMENS and CHESTEL utilize 110 volt or 240 A.C. primary power. These systems could not directly utilize a 48 volt D.C. battery system for back-up power, but an uninterrupted power supply of the type normally used with computer systems could be employed to ensure continued operation during power outages.

Since most of the logic for modern electronic systems operates in the range of 5 to 15 volts D.C., all of the systems operating from a 48 volt battery or from 110 A.C. would likely require some form of duplication of the basic internal power supply operating in this range. Unfortunately, the literature and information obtained from manufacturers does not clearly delineate the extent to which such internal power supplies are duplicated. It is also not clear as to single component failure on system performance. Such uninterrupted power supplies are relatively compact and inexpensive, because of their volume use with commercial computer system.

F. HEAT DISSIPATION

There is a considerable amount of differing opinions in the switching manufacturing segment relating to the means by which heat should be dissipated from the electronic equipment of modern switching systems. Early PCM digital switching systems used fans throughout the entire switch. Currently, only one firm, ROLM, of the firms surveyed in this study, used fans for the entire switch. The remainder of the firms used fans only in the common control section, typically integrated with the minicomputer/microprocessors as supplied by the computer manufacturer. These are typically A.C. fans.

A.C. fans utilizing induction motors are highly reliable, but are subject to interruption when A.C. power is lost, and are not easily supplied from 48 volt D.C. power sources. In contrast, D.C. fans conventionally utilize brush-type motors, which are subject to substantial wear, and generate voltage spikes, etc. which are undesirable in a digital switching system. On the other hand, D.C. motors can easily be run from the 48 volt power supply typically associated with small switching systems. We understand that there is a new brushless D.C. motor which is substantially more expensive, but would clearly be more reliable and not subject to power interruptions from loss of A.C. power supply.

It is interesting to note that NORTH ELECTRIC does not use any fans in the DSS-1 system. However, the maximum ambient temperature allowed is 50° C.

We would conclude that for the size range of switch being considered in this study, that the use of a few fans either of the D.C. brushless, or the A.C. synchronous type would not be a significant contributor to either power consumption or to the reliability of this system. Clearly for all of these systems, either air exchange fans, or air conditioning would be required for van-housing of the system for military field applications.

G. SOFTWARE RELIABILITY

The major source of failures and faults in modern electronic switching systems still proves to be the software associated with the common control section of the system. This is a general statement which applies to larger central office switching systems, but may not apply to the smaller PCM systems with a very limited set of subscriber features. Insufficient experience has been obtained with this class of equipment, or at least insufficient experience reported in the technical journals to draw the same conclusion for this class of equipment. However, software errors are still likely to be a major source of system unreliability within even the smaller system configurations. This will particularly be true if the large range of military subscriber features are provided.

We should like to point out that software failures are most likely to cause short term total system downtime, as contrasted to any single hardware error. Most systems, when encountering a major software fault, reload the basic operating system into the computer from off-line storage, typically losing calls being set up or knocked down. Although our survey indicated the manufacturer's anticipated unavailability of the system in the range of one hour per 20 to 40 years, we have serious doubts that any manufacturer in the world is yet close to achieving such a statistic because of software problems in the system. This strongly suggests that for military applications, to achieve increased overall system availability, one of the following three major actions would appear to be most feasible:

- Utilize the basic software fully field proven in commercial or military applications for a substantial period of time (minimum 18 months).
- Minimize the size and complexity of the software, by minimizing special subscriber features, alternate routing options, etc.
- Assume that a test period of 18 months to two years be employed on any new system brought into the military inventory, which has not been fully commercially tested for at least that length of time. This would substantially delay the introduction of systems into the military inventory, but is one of the few means by which software assurance can be provided.

One can well question, in the light of the software error statistics which have been made available to Dittberner Associates during the course of our PROJECT ESS program, as to whether it is really worthwhile to make major investments in "militarizing" switching systems. This is true when the major source of error in all of these systems remains software problems--at least through the first two to three years of system life. It should also be noted that in the development of a modern electronic switching system that at least 60% of the total development costs are typically devoted to software by the major manufacturers. In a switching system incorporating military subscriber features, the software costs are likely to be in the range of 70% to 80% of the total development costs.

The huge amount of software investment associated with any new switching system, and particularly that of a military-oriented switching system, is extremely large. It constitutes a major portion of the actual procurement price of such systems well into the overall life of the system concept. We, therefore, would strongly recommend that the fewest possible number of different development programs be undertaken. Additionally, we recommend that significant savings could be achieved by minimizing the number of different commercial switches which might be introduced into the military inventory with specialized military subscriber features.

VIII

SYSTEM COST TRENDS

The basis for the information is the Dittberner Associates' PROJECT ESS, A Technology and Management Assessment of Electronic Switching Systems, study program. The information was compeled from a careful study of the hardware design principles of a typical central office of either solid state analog space division technology or PCM time division technology. The study includes a level of detail down to the component level. Then, the anticipated technology and cost trends for electronic components and technology in general were applied to the initial cost of an office using each of the two technologies. Thus, a forecast of the hardware cost for a typical solid state analog local switch of 10,000 lines, as well as PCM local switches of 5,000 and 10,000 lines each, was compiled.

Software costs are based on actual figures for program package sizes, as well as productivity of programmers. Calculation of the cost per system sold is based on realistic assumptions about the typical market achieved by a single product program.

PAM and PWM technology was not included in the PROJECT ESS study program. However, it is expected that the cost of PAM and PWM time division switches will be equal to PCM switches of the same size in the long run. Subscriber line interfaces for either PAM or PWM time division are generally assumed to cost less than PCM subscriber line circuits. However, this difference is largely due to the assumed lesser per line cost of a PAM or PWM modulator and demodulator, as compared with a fully equipped PCM CODEC. A time-shared CODEC, which has the capability to convert 24 or 30 PAM channels into PCM and back, costs $6 per channel as of today. A single channel PCM CODEC in LSI technology is becoming available at $7 in larger quantities right now. Therefore, there is not much room for savings by using a slightly less complex PAM or PWM modulator/demodulator.

While the switching network for a time division PWM system can be expected to be in the same cost range as a switching network for PCM, a time division PAM switching network might cost slightly more. This is because time switched analog crosspoints have to be used as compared with logic gates in the cost of PCM.

Initial Procurement Cost Trends in Electronic Switching Systems

From the results of the proprietary study of long range trends in electronic switching systems conducted by Dittberner Associates, Inc., we present below a nonproprietary summary of long-range cost trends, as they relate to this study program.

- o Integrated circuit analog network equipped stored program controlled switching systems in the range of 10,000 subscriber lines are expected to cost roughly \$300 per line as the initial procurement cost to a typical telephone operating company in the country of origin in 1976. By 1980, in current U.S. dollars, this price would be reduced to approximately \$286 per line. By 1985, this price is expected to be reduced by an additional 10% and by 1990 by an additional 5%--here measured in constant 1980 U.S. dollars.

- o A similar stored program controlled central office with a digital switching network capable of handling 10,000 subscribers would have a sales price in the country of origin to a typical operating company of slighly over U.S.\$300 per line, decreasing to approximately \$250 per per line by 1980. This is expected to further decrease by more than 10% in 1985, and by an additional 10% in 1990--measured in constant 1980 U.S. dollars.

- For a 5,000 line stored program controlled digital local office, the cost per line is substantially less than that for a 10,000 line office, and the cost in 1990 is estimated to be in the range of 60-65% of the 1976 price, measured in 1980 constant U.S.dollars. By about 1978, the cost of a small digital local office to a typical telephone company will be less than that of an equivalent crossbar electromechanical switching system.

- By 1990, the small digital local office will have a realistic initial procurement price some 30-35% less than that of a typical stored programmed reed relay (electromechanical matrix) central office.

NOTE: Detailed proprietary data removed prior to report finalization to permit broad distribution.

IX

COST IMPLICATIONS OF MEETING QUASI-MILITARY SPECIFICATIONS

A. COST IMPLICATIONS OF SPECIAL INTERFACES FOR DATA

1. Solid State Space Division Switches

Solid state space division switches have the inherent capability to be transparent to data of up to at least 64 kilobits per second. The line and trunk interfaces used for telephony purposes, however, contain a voice grade transformer to isolate the line voltages (battery and ringing) from the solid state crosspoints. A special data interface would have to use a specially designed transformer plus special arrangements for signalling and supervision. We anticipate that such an interface would cost $10 more than the standard telephony interface, if manufactured in the same quantities. Depending on the transmission mode used on the line (usually a four-wire loop), additional interfacing is required. Here, the same considerations apply which are given under the heading "Line Mode Interface" in the following section 5.

2. PCM Switches

For data transmission (we include CVSD in the general definition of data transmission), PCM switches seem to have two prerequisites: they are already digital and they are always of a four-wire design internally. On the negative side, they use a fixed data speed of 64 Kbps for each voice channel and there are usually no interfaces for individual 64 Kbps voice channels available with commercial switches.

3. Operating at Reduced Clock Rate to Accommodate CVSD

It appears to be relatively easy to reduce the internal clock rate of a PCM switch in order to allow either 32 or 16 Kbps and voice channel. Thus, CVSD could be used instead of PCM, provided that the right type of line interface is available. Such a reduction of speed, however, does not provide any real advantages. It reduces the available bandwidth per voice channel in order to accommodate CVSD, but no benefit in increased numbers of channels is

derived. Further, it might prove to be difficult to change the rate of the clock because other system components rely on the clock rate.

It appears to be much easier to use only four or two bits of the eight bit PCM word for the CVSD bit stream. The required synchronous bit stuffing can be implemented in the interface at almost no cost at all. However, reduced clock rates might be a solution if a special CVSD matrix is to be designed.

4. Interfaces for Commercial PCM Switches

For the purpose of this study, we assume that a synchronous data (or CVSD) subscriber has to be accommodated, with data speeds of up to 64 kilobits. Lower speeds in a rational relationship to 64 Kbps will allow synchronous bit stuffing. In order to allow synchronization of the subscriber, we assume a line mode (for example, diphase) which carries the bit clock to the subscriber. This will enable the subscriber to restore the original clock signal and to use it as a transmit clock. We further assume a suitable frame format for word-oriented transmission (not usually required for bit-oriented data as CVSD). Further, we assume that the interface at the switch will fit any data which arrives at less than 64 Kbps into the internal PCM bit stream and will only transmit the essential bits to the other party. We further assume that a suitable digital signalling code be used between the subscriber and the switch to indicate on/off hook conditions, busy signals, as well as to transmit the dialing information to the switch. NOTE: The signalling concept becomes much easier if a "PCM subscriber" is assumed. In this case, the CODEC and associated circuitry would be placed in the telephone instrument. The data loop and everything else then becomes transparent for DTMF, as well as for busy and dial tones. Only ringing has to be transmitted in some acceptable way to the subscriber.

In the following, we will consider the design and cost aspects of the main parts of such a digital interface.

5. Line Mode Interface

Digital signals have to be transmitted in a suitable "base band" line mode. There are dozens of known schemes for this purpose. The diphase scheme is among the simpler ones and serves the additional purpose of continuously transmitting a clock signal to the other end, even if no data are transmitted. Complexity of such a circuit depends on the complexity of the signal recovery circuitry, which determines the maximum distance such units can communicate with each other on two normal twisted pairs of wire. There has to be an equivalent unit at the subscriber end of the line.

Diphase data transmission involves the use of base-base A.C. techniques, with basically a pulse-width approach utilized to indicate the presence or absence of a "1" bit during a fixed sampling interval. This digital transmission mode does not contain any D.C. component--although it is often considered as a type of "telegraph" technique.

A simple diphase interface for a four-wire loop would allow communication of over 6,000 feet at 64 Kbps. A more complex one could be used for up to several miles. Both have to include the necessary circuits for overvoltage protection. We assume that manufacturing cost for the simple interface would be $100 to $180 for the complex one. Development cost could run up to about $10,000 for the simple one and several times as much for the complex circuit, unless applicable experience is available. Manufacturing cost may be expected to come down, if the volume warrants specially designed integrated circuits.

6. Digital Interface to the Switch

In a normal PCM subscriber circuit, the CODEC (assuming that one CODEC per line is used) has two separate, buffered eight-bit interfaces on its digital side: one for transmission of encoded data and one for reception of data to be decoded. Additional signals control all the necessary sequences. It appears that a usual USART (a standard LSI circuit, performing the function of a Universal Synchronous/Asynchronous Receiver/Transmitter) has very

similar parallel data interfaces and may be relatively easily adapted for our purpose to convert data between serial and parallel format. It is likely, however, that some kind of additional buffering may be required. Here also off-the-shelf LSI circuits can be used, namely the type called a "First In/First Out" or FIFO memory. This is a LSI memory, which comes in modular units and which has on-chip control to interface with UARTS and related components. Quite a number of logic functions are required to interface between the digital signalling used on the subscriber loop and the line supervision circuitry (scanners and drivers) of the PCM switch. In addition, removal and insertion of framing bits, synchronous bit stuffing and similar tasks are required. Further, it might be desirable to be able to change the data transmission speed of the interface either by setting a switch manually, or even under control of the common control processor of the switch. All of these functions could easily be performed by an inexpensive one- or two-chip microprocessor. The necessary programs would be implemented in the ROM which is part of the chip or chip set. There are also various LSI circuits available which allow generation of all standard transmission clocks for data communication applications for a standard fixed clock and permit the change of the speed under control from a microprocessor. We assume the following cost breakdown for such an interface:

COMPONENTS	PRICE RANGE
LSI elements, incl. of microprocessor and ROM	\$40 to \$80
Other components, inclusive of I.C.'s	\$30 to \$60
Components for that part of the interface which is identical with a section of the voice type of subscriber circuit	\$20 to \$30
Total Components	\$90 to \$170
Interface packaging and assembly cost: assembly cost, inclusive of testing	\$120 to \$250
Total Cost of One Interface:	\$210 to \$420

To this amount, the cost of the diphase interface has to be added. However, the digital interface just described could be manufactured for less cost if the expected volume would justify design of special LSI circuits. Also, an interface just for a digital PCM telephone instrument would be less expensive, because only one data speed is involved and no special signalling, except for ringing. Similar simplifications are to be expected for an interface which accepts CVSD only. On the other side, a data interface similar to those usually found on data switches, and which can perform "handshake" routines of varying complexity and re-format data streams will be considerably more complex and costly.

Development cost of such an interface should be in the range of $60,000 to $100,000, depending on the complexity and the amount of software programming involved.

X

PROPOSED AREAS FOR ADDITIONAL STUDY

The following areas that require significant additional study effort have been identified.

A. CVSD MULTIPLEXING AND INTERFACE TO PCM

The questions involved in the handling of continuously variable slope delta modulated voice signals requires additional study to determine how this can be effectively handled with the more advanced PAM and PCM systems. Further, the question as to how such transmission techniques can be provided with a conferencing capability also requires additional effort. Currently the only digital-level conferencing systems for CVSD in the United States are being developed by Collins and Motorola. Some equipment for interface between CVSD and PCM transmission techniques is, we understand, being developed at the Rome Air Development Center (on a per channel basis, not multiplexed).

It appears that an effort in the range of 20 to 30 mandays may be required to obtain an adequate overview of this problem.

B. COST ANALYSIS OF HIGH SPEED DATA TRANSMISSION THROUGH PCM SWITCHES

Substantial additional effort should be exerted in determining the technical approach and rough cost associated with the handling of CVSD data streams, 64 kilobit data streams and lower speed data streams through a PCM switching system. The problems associated with synchronization of such data streams, the general approach to bit stuffing techniques, and the general design problems of the line interface to permit such data streams to be passed effectively through the PCM switch should be investigated.

We estimate that the effort required to address this area would be in the range of 20 to 25 man-days. This would provide a rough analysis of the general and cross-technical approaches which would prove feasible.

C. SURVEY OF ACHIEVED RELIABILITY IN SMALL SWITCHING SYSTEMS

This survey effort did not include a gathering of achieved reliability information from users of all electronic switching systems in the size range 100 to 5,000 lines. We believe that an effort specifically dedicated to this purpose would prove most useful to the Department of Defense, and we recommend that it be undertaken. Stres should be placed on gathering this information directly from the end user where possible, rather than from the manufacturer.

We estimate that this effort would require in the range of 15 to 20 man-days.

D. CONCEPT STUDY IN INTEGRATED SWITCHING AND TRANSMISSION FOR MILITARY APPLICATIONS

We believe it could be most valuable to the Department of Defense to have an independent concept study of feasible approaches at integrated digital switching and transmission facilities within the military establishment, particularly considered to be an extension of the current survey effort where various economic trade-off studies could be undertaken. This particularly relates to the bandwith requirements for normal commercial PCM versus those for the various nonlinear delta modulation approaches currently being developed or deployed by the U.S. military. Unlike some of the studies being undertaken by the Defense Communications Agency, we propose that such a effort would be based upon feasible approaches to be taken during the next five years. It should specifically address the question of integration of military systems with both commercial telephone systems, and with commercial PCM carrier and PCM switching equipment available within that time frame. A more in-depth review would be made of the concepts for dynamic allocation of bandwith between voice and data requirements (RCA-DCA concept) and an evaluation undertaken of the possibility of adapting commercial equipment to meet this general requirement versus the

embodiment of the fully integrated voice and data switching concept now being explored by RCA. Here, the objective would be to determine whether or not the general developmental effort, if brought to completion and fabrication would be cost effective even within the same order of magnitude as some acceptable solution to the need utilizing commercially developed approaches.

This effort would likely be sizeable. We doubt if little meaningful results could be developed for an investment of less than 40 to 60 man-days. Clearly an effort of this nature could be extended into several man-years if a really comprehensive study this nature were to be undertaken.

APPENDIX A

GLOSSARY OF SWITCHING TERMINOLOGY

GLOSSARY OF SWITCHING TERMINOLOGY[1]

Alternative Automatic Routing - The action of a common-controlled office in sequentially testing trunks over several alternate routes in attempting to complete a call.

Amplitude Modulation - Process by which a continuous "carrier" wave is caused to vary in amplitude corresponding to the amplitude of the modulating signal.

Blocking - The inability of the calling party to be connected to the called party because (a) all paths are busy, or (b) because idle paths in the calling group cannot access paths in the called group.

Bus - A heavy conductor, or group of conductors, to which several units of the same type of equipment may be connected.

CENTREX Service - Service providing direct inward and outward dialing for PABX extensions. The PABX is assigned a distinct central office code, and made a part of the numbering plan. A main listed number will give access to the PABX operator.

Circuit Switching - A method of handling traffic through a switching center by interconnecting incoming and outgoing circuits.

Class-of-Service Mark - A connection, or a signal, which provides information regarding the class of service to which a particular subscriber is entitled.

Code Call Access - Allows attendants and station users to dial an access code and a two or three-digit called party code to activate signalling devices throughout a customer's premises with a coded signal corresponding to the called code. The called (or "paged") party can then be connected to the calling party by dialing a "meet-me" answering code from any station within the PBX or CENTREX system.

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[1] Smith, Emerson C. Glossary of Communications, Telephony Publishing Corporation, 1971

Common-Channel Interoffice Signalling (CCIS) - A method of transmitting all signalling information for a group of trunks by encoding it and transmitting it over a separate voice channel using time-division digital techniques.

Common-Control - Describes an automatic telephone system in which the dial pulses from the calling telephone (which constitute the address of the called telephone) are registered, analyzed, and re-sent in the form of a routing code to operate switches as required to establish the desired connection.

Controlled Rectifier - A rectifier using a "silicon controlled rectifier" (SCR) as the rectifying element. The SCR can be triggered at any point in the alternating current cycle to control the current.

Crosspoint - A single inlet, single outlet switch used to construct a switching matrix.

Crosstalk - Unwanted coupling from one signal path to another. Faint speech or tone heard in one circuit, coming from an adjacent circuit.

Delta Modulation - A digital modulation, in which a signal representing the difference between the amplitude scheme of a sample and the amplitude of the previous sample is sent. Operates well in the presence of noise, but requires a wide frequency band.

Demultiplexer - A device that reverses the action of a multiplexer, and derives a group of separate channels from the complex multiplex signal.

Digital Circuit Switch - A switch used to interconnect circuits between users for the real-time transmission of digital signals.

Field Effect Transistor (FET) - A tiny bar of n-type semiconductor having opposite spots of p-type material. Application of a negative bias to the p-type regions controls their space charge region which controls through resistance of the n-type bar.

Indentified Outward Dialing - Provides either automatic or attendant identification of the calling station line number to permit station billing on toll calls. The term, "AIOD," refers to the capability of the system (and not off-board supplemental equipment) to provide this automatically by some type of "print-out." One can expect a high cost associated with the AIOD feature offering.

In-band Signalling - A type of signalling using an AC signal within the normal voice band. This signal can be transmitted from end to end of a long voice circuit without any intermediate signalling equipment must be arranged for "tone on when idle" operation. Since the signal is audible the signalling equipment must be arranged for "tone on when idle" operation.

Line Balance - The degree of similarity between the two conductors of a communication line. Balance implies equal resistance, equal inductance, equal capacitance to ground, and equal leakage to ground. A balanced line will be free of noise and crosstalk.

Lineswitch - An automatic switch which connects a (subscriber's) line to an idle trunk within a group of ten. If used as a "primary lineswitch," it has associated with it the "subscriber's line equipment."

Modem - A single unit of equipment which combines the functions of modulator and demodulator. This is an economical arrangement, since the two circuits can use common elements.

Multiplex - Equipment which provides a means of transmitting two or more signals over the same transmission path.

Non-Blocking - Describing a switching network having a sufficient number of paths such that a subscriber originating a call can always reach any other idle subscriber without encountering a busy.

Out-of-Band Signalling - An AC tone signalling system which uses a frequency which is within the pass band of the transmission facility, but outside of the voice band. Compandors are not affected by such a tone and signalling can, if required, take place during the talking condition. The type "N," "O," and "ON" carrier equipments use out-of-band signalling.

PABX (FOR ALL PRACTICAL PURPOSES ALSO EQUIVALENT TO PBX) - Telephone switching equipment utilized on a dedicated basis for interconnecting the stations located on a subscriber premises between themselves, and the public dialed network. PABX stands for Private Automatic Branch Exchange, which distinguishes these from PBX's in that the connection is made automatically through dial manipulation rather than manually, which may be the case in PBX equipments. However, since very few manual PBX's are being built, the two terms are essentially synonymous, i.e., almost all PBX's are PABX's.

PAX (PRIVATE AUTOMATIC EXCHANGE) - This is telephone switching equipment similar to a PABX, except for the fact that no connection is permitted with the public dialed network.

MANUAL PBX - Any PBX not having the capability for station-to station dialing but requiring operator assistance for any and all connections.

Progressive Conference - Conference in which an operator calls each participant in sequence as instructed by the initiator, notifies the party of the conference, and connects he or she to the group.

Pulse Code Modulation (PCM) - The conversion of an analog (voice) signal to a digital code. The analog signal amplitude is sampled at a rate more than twice the signal frequency, and the amplitude of each sample is transmitted as eight-bit code.

Pulse Width - The time interval between points on the leading and trailing edges of the pulse at which the instantaneous value has a specified relation to the peak pulse amplitude.

Rectifier - An electrical device for converting alternating current to direct current. Implies an output which is not pulsating, and is reasonably free from noise components. The term rectifier does not apply to a rotary machine, such as a rotary converter.

Redundancy - Any excess of signal elements over those required to carry the message. Speech is a highly redundant form of message coding. Certain data signals have no redundancy in themselves, and must use an extra redundant data bit for error checking. The fraction of the total information content of a message which can be eliminated without loss of meaning.

Reed Relay - A relay composed of reed units consisting of contacts on moveable magnetized reeds sealed into small glass tubes. Coils around the glass tubes are pulsed with a current to operate the reed.

Tandem - A switching arrangement, in which the trunk from the calling office is connected to a trunk to the called office through an intermediate point known as a tandem switching center.

Time-Division Multiplex - Arrangement where several signals share a single transmission facility, each being connected in sequence for a short period of time.

Transformer Coupling - A transformer used to couple two circuits by means of its mutual impedance

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